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GEOHYDROLOGIC EVALUATION OF A PROPOSED COAL-ASH  
DISPOSAL SITE NEAR MANDAN, NORTH DAKOTA

by  
David M. Ronnei

Bachelor of Science, St. Cloud State University, 1985

A Thesis

Submitted to the Graduate Faculty

of the

University of North Dakota

in partial fulfillment of the requirements

for the degree of

Master of Science

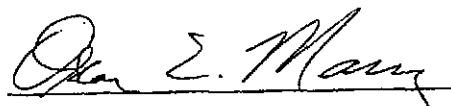
Grand Forks, North Dakota


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1987

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This thesis submitted by David M. Ronnei in partial fulfillment of the requirements for the degree of Master of Science from the University of North Dakota has been read by the Faculty Advisory Committee under whom the work has been done, and is hereby approved.

  
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This thesis meets the standards for appearance and conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

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## ABSTRACT

Montana-Dakota Utilities Company (MDU) operates Heskett Station, a 100 megawatt coal-fired power plant, located near Mandan, North Dakota. In the process of generating electricity, MDU's Heskett Station produces approximately 62,000 tons of coal-ash annually. The ash has been disposed of by above-ground stockpiling on the plant site for the past 35 years. Limited storage space and new solid waste regulatory restrictions have necessitated the search for a new ash disposal site.

This investigation focused on selecting a disposal site that would be suitable for long-term disposal of coal-ash generated at Heskett Station. Specifically, the objective was to locate a site that would require minimal engineering redesign and use in situ materials for leachate containment and trace element attenuation. Several areas were considered and ultimately one site was selected for detailed geohydrologic evaluation.

The site which is being proposed for ash disposal is located approximately one-quarter mile west of Heskett Station. A total of 27 monitoring wells were installed at the proposed site. Monitoring well water levels indicated the presence of a static water table which is generally 30-40 feet below the ground surface. The groundwater beneath the proposed site is flowing north-northeast. Potentiometric levels indicate that there is a strong downward component of groundwater flow over the entire proposed disposal site (recharge area).

Chemical analysis of water samples obtained from the various monitoring wells at the proposed site indicate that the shallow ground-

water is highly mineralized with total-dissolved-solids (TDS) concentrations commonly exceeding 8,000 mg/L. The groundwater existing in the pre-disposal setting is of similar quality to the simulated ash leachate generated during EPA-EP toxicity testing. Cadmium, arsenic and lead were the only trace elements leached from the ash which slightly exceed primary drinking water standards.

During the operational phase of ash disposal the objective should be to minimize leachate production by continual reclamation of ash-filled "cells". Covering the cells with low permeability excavated materials, along with the high climatically induced evapotranspiration, will minimize infiltration and thus leachate production. A dry disposal setting can be further assured by maintaining a 5- to 10-foot buffer/attenuation zone between the pit bottom and the elevation of the highest recorded water table. If these disposal site design criteria are followed, coal-ash emplaced in this proposed facility will have a minimal impact on groundwater quality and, in general, on the geohydrologic flow regime.

## ACKNOWLEDGMENTS

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I would especially like to thank Dr. Frank Beaver for introducing me to this project and for his guidance throughout the course of the project. I would also like to thank him for lending his expertise and helping me with field work during certain critical stages of this investigation.

My education at UND was greatly facilitated by a grant from MontanaDakota Utilities which was awarded to the North Dakota Mining and Mineral Resources Research Institute. I was fortunate to receive an assistantship from the MMRRRI to work on this project for a period of two years.

I would like to thank Montana-Dakota Utilities for funding this entire project. My appreciation goes out to all of the MDU personnel who assisted me during this project, in particular; John Verwey, Bruce Imsdahl, Wayne Moe, Dr. Neill Burnett and Jeff Stanford.

## INTRODUCTION

Montana-Dakota Utilities Company placed R.M. Heskett Station Unit 1 in service in late 1954. At that time, Unit 1 was the world's largest spreader stoker lignite-fired steam generator with a rated turbine capacity of 20,000 kw (MDU, 1954). During the late 1950's demand for electricity in the Bismarck-Mandan area grew at a steady pace, and in 1959 design plans were undertaken for Heskett Station Unit 2, which was to be located adjacent to Unit 1. In 1963 Unit 2 was placed on-line with a generation capacity rated at 66,000 kw. When operating at peak capacity the combined rated output of Units 1 and 2 was nearly 90,000 kw with a lignite consumption rate of nearly 105 tons per hour.

In the process of generating electricity from lignite, R.M. Heskett Station produces approximately 39,000 tons of lignite ash annually (Armstrong and Schmid, 1986). This figure will increase to nearly 62,000 tons in early 1987. The increase in ash production will be the result of the installation of a new fluidized bed steam generation system which is currently being retrofitted within Unit 2. When the new system goes on-line, the refurbished Unit 2 will have a rated turbine capacity of 73,000 kw. The fluidized bed system is being installed in order to alleviate the problem of water tube slagging which has plagued the large stoker (previous Unit 2) since it began generating electricity. The fluidized bed system will burn coal more efficiently with less slagging which, in turn, will allow for a higher output of electricity and much less maintenance.

Since the inception of Unit 1 in 1954, and with greater contributions from Unit 2 beginning in 1963, R.M. Heskett Station (Heskett Station) has produced approximately 810,000 tons of lignite ash (Armstrong and Schmid, 1986). This entire quantity of coal-ash has been disposed of in an aboveground stockpile immediately north of the plant. Even though the ash is nontoxic, according to the EPA-EP toxicity test, problems have arisen from blowing ash and from runoff carrying the ash into surface waters such as the Rock Haven Creek and the Missouri River. The problems associated with current ash disposal practices at Heskett Station have led the North Dakota State Department of Health (NDSDH) to order Montana-Dakota Utilities (MDU) to seek new and more effective ash disposal methods.

## Objectives

The main objective of this investigation was to locate an area that would be intrinsically suitable for the long-term disposal of lignite-ash generated at Heskett Station. Specifically, the objective was to locate a site that would require minimal engineering redesign and use in situ materials for leachate containment and trace element attenuation. Economically, it was critical that the disposal site be located as close to Heskett Station as possible. The site chosen for disposal must also meet all requirements set forth by the North Dakota State Department of Health and the U.S. Environmental Protection Agency (EPA).

The United States generates more than 200 million tons of coal-ash each year. Approximately 1.75 million tons of coal-ash are produced annually in North Dakota (Groenewold et al., 1985). At this time less than one-fourth of the ash produced on a national basis is utilized in various ways; the remainder is placed in disposal sites (Suloway et al., 1983). The most common and cost effective method of ash disposal in use today is landfilling (Summer et al., 1983). However, there are several potential problems associated with this type of disposal method. One of the major concerns is leachate generation which often leads to groundwater contamination. Another associated problem is the degradation of the landscape caused by opening the entire disposal pit-area at the beginning of landfill operations. This is generally a prerequisite for disposal because the entire area must be opened in order to install the containing or lining material, which is generally compacted clay or synthetic fabric. Often, the potential for groundwater degradation can be minimized by the use of natural in situ lining materials such as clay

and silt. The use of in situ lining materials permits the opening and closing of small portions of the disposal site over short periods of time. A portion of this investigation was devoted to finding a site which possessed texturally desirable materials that would effectively manage leachate; materials with properties similar to those of an engineered/installed liner.

During the course of this investigation several sites were considered for coal-ash disposal and ultimately one site was selected for detailed geohydrologic evaluation. The site selected for evaluation (the proposed coal-ash disposal site) is located one-quarter mile west of Heskett Station and is on MDU property. Hereafter, this proposed disposal site will be referred to as the "Heskett site".

The specific objectives of the evaluation of the Heskett site were:

1. To determine the three-dimensional distribution of the subsurface geologic materials.
2. To determine the aquifer configuration.
3. To determine the water table elevation and aquifer characteristics.
4. To determine the direction and rate of ground water flow.
5. To determine the background chemical composition of the groundwater at the primary site (Heskett site).
6. To determine the chemical, mineralogical and physical characteristics of the coal-ash.



## Previous Work

Management personnel of each coal-fired power plant operating in the United States must make a decision as to where to dispose of their coal-ash. In North Dakota, because most facilities are mine-mouth operations, the most common disposal practice is to put the coal conversion ash back into the strip-mined area and reclaim it along with the rest of the mined land. However, Heskett Station is approximately 50 miles from the coal mining area making it economically infeasible to transport the ash back to the mine for disposal.

With the large volumes of coal by-products produced annually in this country, many utility companies are faced with major questions regarding management of coal-ash materials. Although utilization of ash is increasing, the most common approach to disposal is burial in landfills. One of the primary concerns associated with burial of coal conversion waste products is the potential impact they may have on groundwater supplies. Leaching studies have shown that coal by-products, in particular fly ash, produce highly mineralized solutions. Often these mineralized solutions contain trace elements such as arsenic, selenium, cadmium, lead, chromium, molybdenum, iron, manganese and zinc in varying concentrations which are dependent upon the source coal.

Implications of the Resource Conservation and Recovery Act (RCRA) of 1976 focused necessary attention on coal conversion waste disposal problems. Since 1976 major research efforts have been launched to characterize this abundant waste material so that it can eventually be disposed of or utilized in an economically feasible manner. Research has

been sponsored by several groups including the Electric Power Research Institute (EPRI), Gas Research Institute (GRI), Department of Energy (DOE), and the Environmental Protection Agency (EPA).

Recently, utilization of coal by-products has become a major area of research for many organizations and universities. Oscar Manz, Director of the North Dakota Mining and Mineral Resources Research Institute's Coal By-Products Laboratory at the University of North Dakota, is a leading figure in this rapidly-growing field. Each year more economical uses of coal conversion ashes are found. Currently, some of the major uses of this material include road-bed stabilization and cement mixture additives.

This thesis is based largely upon previous research in coal conversion ash characterization and disposal methods completed by the Mining and Mineral Resources Research Institute (MMRRI) at the University of North Dakota. Several other groups are actively investigating coal conversion ashes; however, most of that research has focused on eastern coals and coal-ashes. Major chemical and mineralogical differences exist between these coal and ash types and, consequently, they produce distinctly different leachates. For example, eastern ashes generally produce acidic leachates while western ashes produce alkaline leachates.

Summer et al. (1983) presented a report to EPRI on the physical and chemical characteristics of coal conversion solid wastes. This report focused largely on trace elements which were leached from the solid wastes. In 1985, Summer et al. compiled a report on field impacts of utility solid waste disposal sites. Six waste disposal sites were investigated. Summer et al. concluded that the major ions Ca, Mg, K,

Na, Cl and  $\text{SO}_4$  and several trace elements including As, Se and Cu were leached from the ash waste masses and contributed to the groundwater. Also noted in this investigation were possible attenuation mechanisms which were responsible for lowering concentrations downgradient from the disposal sites.

McCarthy et al. (1983) discussed the mineralogical controls on toxic trace element contamination of groundwater from buried utility solid wastes. This investigation concentrated on fly and bottom ash generated from two power plants in western North Dakota. The dominant mineral phases identified in both types of ash were quartz, periclase, ferrite spinel, anhydrite and lime. The importance of mineralogical characterization was stressed as a governing agent in determining the behavior of coal conversion ash when it is emplaced in the ground for disposal or utilized for some other purpose such as a cement additive or replacement. McCarthy et al. (1984) expanded their mineralogical characterization studies and began to compare western coal ashes with eastern coal ashes and concluded that western ashes generally contained higher calcium, magnesium and sulfate mineral phases.

Suloway et al. (1983) investigated the chemical and toxicological properties of coal fly ash. This study compared Illinois Basin fly ash with western fly ash. The ash for the two western fly ashes studied originated from coal mined in western North Dakota. The study determined that eastern coals and subsequent ashes contain greater amounts of potentially toxic trace elements. This difference was attributed to differences in leachate pH between western coal (lignite) and eastern coal mined from the Illinois Basin. In general, the eastern

fly ashes produce more acidic leachates and western fly ashes produce much more basic leachates.

Johnston et al. (1983) studied the movement of trace elements in a fly ash disposal site near Courtright, Ontario which had been actively receiving ash since 1969. The disposal site was constructed in a clayey till, which they found to be effective at attenuating the trace elements: arsenic, selenium, cadmium and zinc. Their studies led them to conclude that clay

Jackson and Moore (1984) investigated fossil fuel waste sampling and characterization techniques and determined that EPA leaching tests were not directly applicable to fossil fuel wastes. DOE, along with the American Society for Testing and Materials (ASTM), developed a more applicable leaching test for fossil fuel and coal conversion wastes. The new method more closely approximates actual field leaching conditions than did the EPA leaching tests. Over 19,000 extraction tests were run on fossil fuel waste material. None of the coal conversion ashes tested were classified as hazardous according to current regulations.

Koob and Groenewold (1984), discussed the alkaline neutralization capacity of west-central North Dakota overburden materials. This investigation focused on the buffering capacity of overburden materials and the ability of these materials to neutralize high pH leachates generated by western fly ashes. All of the overburden materials tested significantly neutralized high pH (10-12.5) leachates. They concluded that other buffering mechanisms, in addition to the carbonate-bicarbonate system, were active in neutralizing these alkaline leachates. Cation exchange was noted as the additional mechanism. They further concluded that liners for coal-ash disposal sites located in the

Tertiary sediments of North Dakota were unnecessary because the pH buffering system would effectively control the mobility of toxic trace elements. The conclusions within this report were significantly complemented by previous work by Groenewold et al. 1980 and Groenewold et al. 1983.

Groenewold et al. (1985) began to investigate the controls on toxic trace element concentrations in western fly ash leachates. Elements of particular concern in this investigation were arsenic, selenium and molybdenum. From field and laboratory data they were able to show that trace element concentrations in coal-ash leachates were a function of pH. As the pH's were buffered from initially high values, trace element concentrations decreased. Also indicated as a control on leaching was the cementitious behavior of coal-ashes. Once the ash "sets-up", very little leaching can occur. They concluded that intrinsic conditions at most potential Northern Great Plains ash disposal sites in Paleocene strata were capable of promoting attenuation of elevated pH and critical trace elements in coal-ash leachates.

In 1986, Hassett and Groenewold summarized the results of a laboratory investigation into the attenuation capacity of overburden deposits of central and western North Dakota. Sandy-silt and clay, both oxidized and unoxidized, were the materials analyzed for attenuation capabilities. Parameters of the solution included: arsenic, selenium, molybdenum, cadmium, iron, calcium, sodium and sulfate. They found that iron was removed by the overburden sediments in excess of 99 percent. Cadmium was removed in excess of 95 percent, and as expected, was pH dependent. Cadmium and other metals tend to precipitate as hydroxides

and hydroxide-carbonates at pH values above 6.5. Arsenic was also highly attenuated (between 50 and 95 percent), with the greatest attenuation occurring within the reduced and oxidized clays. They found that arsenic was highly mobile at high pH's (11-12) and as pH decreased so did arsenic mobility. Molybdenum was the only parameter that went through the system totally unattenuated. The conclusion of their investigation was that the Tertiary surface mine overburden materials of western North Dakota have a strong capacity to buffer pH and attenuate arsenic, selenium, iron and cadmium which are trace elements commonly leached from coal conversion ashes.

Beaver (1986) summarized a long-term field study of a coal conversion waste disposal site and arrived at the same general conclusions Groenewold et al. (1985) and Hassett and Groenewold (1986) made in their laboratory and field studies. He found that the pH of the leachate generated within the ash itself was very high (10-13) and at these elevated pH's several trace elements were highly mobile. pH was rapidly buffered to an equilibrium range (6-9) when the leachate came in contact with surrounding sediments. Arsenic, selenium, cadmium, lead and chromium were all attenuated and maintained at low levels once outside of the active ash disposal area. He concludes that the installation of liners in similar settings (clay and silt in coal-bearing strata of western North Dakota) is unnecessary if their purpose is to contain and attenuate trace elements. The trace element attenuation mechanism is already effectively in-place in these settings.

This thesis applies conclusions from the above investigations in a multidisciplinary manner to evaluate and select an area for long-term

coal-ash disposal. The previous work was used as a general guide during the course of this investigation.

### Study Area Location

Heskett Station is located approximately 3 miles north of Mandan, North Dakota. The study area for this project began as an area which included all land within a 20 mile radius of Heskett Station. Potential site areas, candidate sites, final sites and ultimately the primary site were selected from within this large study area (Figure 1).

Five candidate sites for coal-ash disposal were selected from within this large study area and ultimately two sites were chosen for comparative evaluation. The two final sites are depicted in Figure 2. The Heskett site (primary site) is located immediately west of Heskett Station and is the site which is being proposed for coal-ash disposal (Figure 2). The location of a secondary site, originally denoted as "site 6", is also depicted in Figure 2. The remainder of this thesis will focus on the selection and evaluation of the Heskett site.

The Heskett site has a total area of  $0.5\text{mi}^2$  ( $.80\text{ km}^2$ ). Physiographically the Heskett site is within the Great Plains Province (as is all of Morton County), an area characterized by low buttes and gentle sloping hills. The study area is bound on the west and north by the Rock Haven Creek, which is an ephemeral stream that drains a relatively small area to the west. The site is bound on the east by Heskett Station and the existing ash pile and on the south by 43rd Street Northeast which is a one-mile long section road that divides MDU property on the north from Amoco (Mandan Refinery) property on the south.

Figure 1. Location of study area.



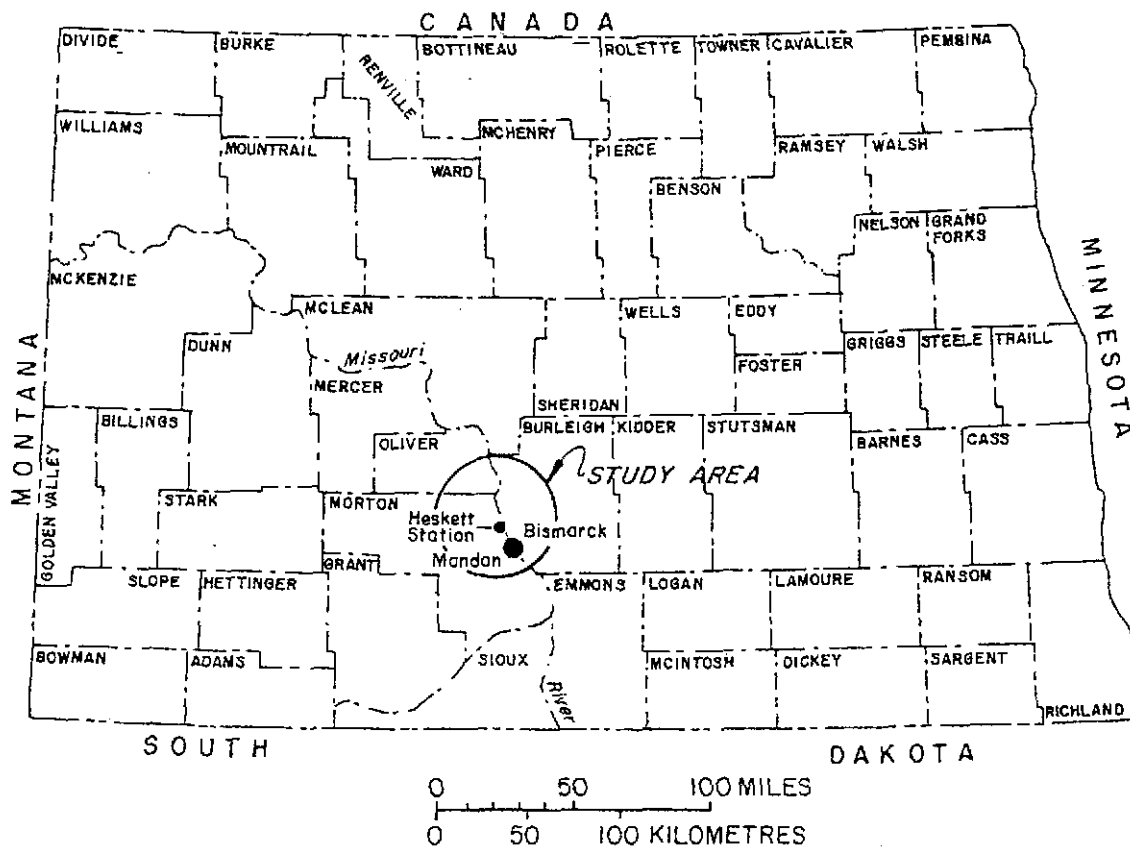
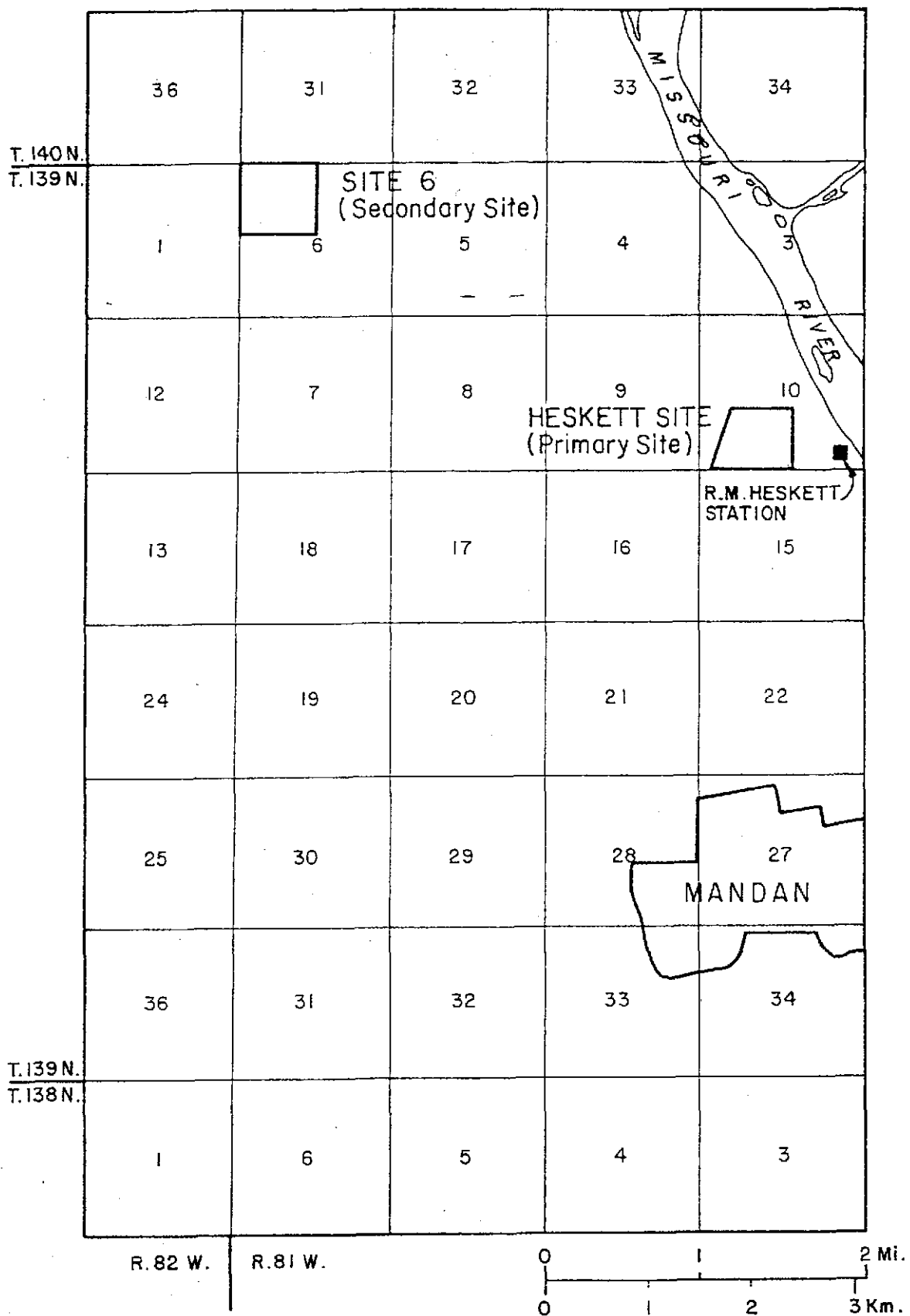


Figure 2. Location of the primary site  
(Heskett site) and the secondary site (site 6).



### Location-Numbering System

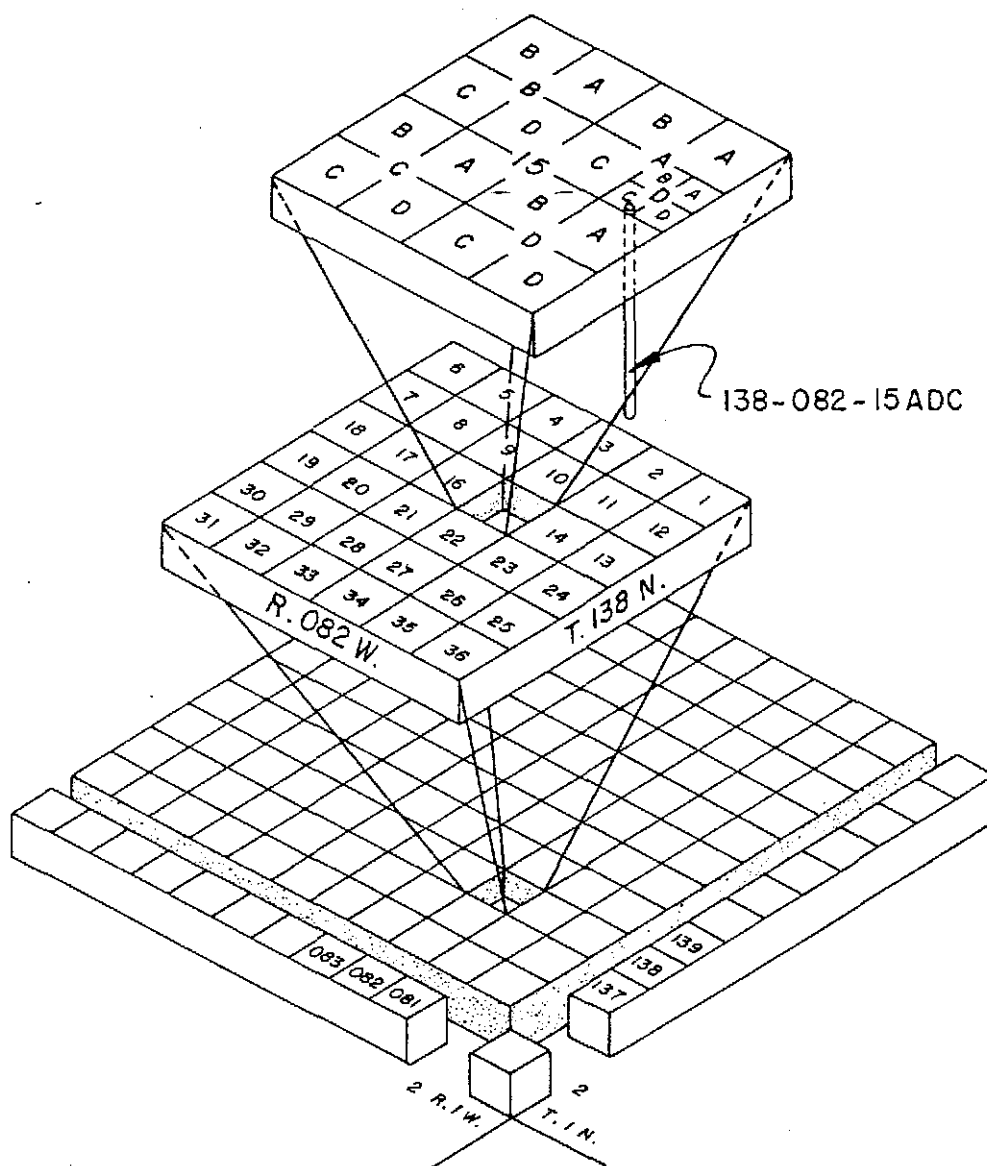
The wells and specific data sites within this report are numbered according to the system of land survey used by the U.S. Bureau of Land Management. The system is illustrated in Figure 3. The first numeral denotes township north of a base line, the second numeral denotes the range west of a base line and the third numeral denotes the section in which the site is located. The letters A, B, C, and D refer to the northeast, northwest, southwest and southeast quarter sections (or quarter-quarter or quarter-quarter-quarter sections), respectively. For example, well 138-082-15ADC is located in the SW1/4 SE1/4 NE1/4, sec. 15, T. 138 N, R. 82 W.

### Climate

The climate of Morton County and the Heskett site study area is semiarid with widely ranging seasonal temperatures. Summer temperatures may exceed 100°F (38°C) while winter temperatures may drop below -40°F (-40°C). The mean average annual temperature at Mandan is 41.4°F (5.2°C). The average annual precipitation at Mandan is 16.77 inches (42.6 cm). Approximately 60 percent of the annual precipitation occurs as rain during a four month period beginning in April and extending through July (U.S. Department of Commerce, 1973).

On the average there are about 125 frost-free days in this region of North Dakota. The mean depth of frost penetration is 4.5 feet (1.4 m), but during extremely cold winters the frost may penetrate to a depth of 7.0 feet (2.1 m) (Jensen, 1984).

Figure 3. Location-numbering system for wells installed at the Heskett site (from Ackerman, 1977).



### Ash Production

The weight of ash generated annually at Heskett Station since 1963, when both units were on-line, has been approximately 39,000 tons. When the fluidized bed system becomes operable in early 1987, this figure will jump to nearly 62,000 tons annually. Most of the increase in tonnage will be the result of co-disposal of sand from the fluidized bed along with the bottom ash. The actual weight of the ash produced annually, without the sand, will be approximately 45,216 tons (Verwey, personal communication, 1986). However, the sand is considered to be part of the bottom ash because it is actually coated and interspersed with bottom ash slag. The sand will be disposed of with a mixture of bottom and fly ash. Table 1 shows the estimated annual tonnage and volume of ash for each of the 2 units operating (or soon to be operating) at Heskett Station.

Figure 4 illustrates that 26.1 percent of the annual waste material generated will consist of relatively inert sand. Approximately 49.2 percent of the material to be disposed of will consist of fly ash and the remaining 24.7 percent will consist of bottom ash.

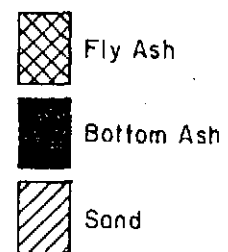
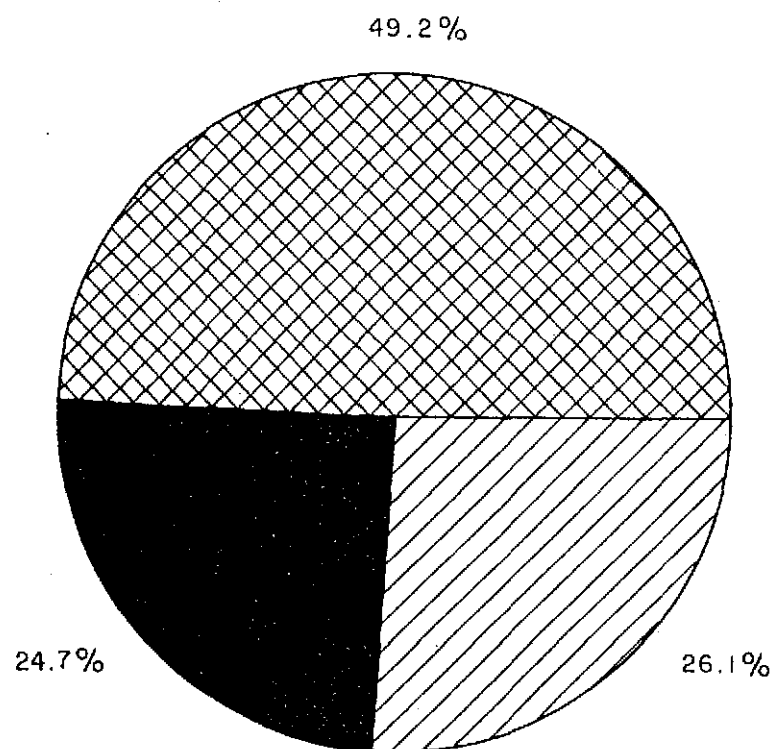
The remaining in-service life of Heskett Station Unit 1 is estimated at 20 years, during this time period it will produce approximately 175,400 tons of ash. The volume of ash produced by Unit 1 during the next 20 years will be approximately  $4.05 \times 10^6 \text{ ft}^3$ . The in-service life of Unit 2 is expected to be 30 years. During this period of time Unit 2 will produce approximately 1,569,000 tons of ash (including sand), which will have a volume of about  $3.66 \times 10^7 \text{ ft}^3$  (Verwey, personal communication, 1986). The proposed ash disposal site

Figure 4. Percentage (by weight) of fly ash, bottom ash and sand to be disposed of on an annual basis. Includes ash from both Units 1 and 2.



# ANNUAL ASH PRODUCTION

Percent by Weight



## METHODOLOGY

### Site Selection

Near-surface sediments characterized by high clay and silt content and gentle topography were prime considerations during the disposal site selection phase of this investigation. Clay and silt were considered the most important factors during site selection because these materials typically transmit groundwater at very slow rates, which in turn helps to prevent the migration of leachate into subsurface water supplies. Another important consideration was the attenuation capability of the subsurface geologic materials. Clay and silt generally have higher attenuation capabilities than do other typical sediments (Drever, 1982).

In order to realize the goals of this project a relatively large area of study had to be considered (Figure 1). One of the main project goals was to select a site which would have near-surface (upper 30 feet) materials possessing characteristics similar to those of typical liner materials. Transportation and hauling costs were weighed against the cost of selecting a geologically-marginal site very near to Heskett Station and installing a lining material. After investigating several sites and outlining areas of clay-rich lithologies it became apparent that suitable, and even preferable, areas for ash disposal existed very near Heskett Station.

Three phases of site selection were used to arrive at the location of the "primary site" (the Heskett Site): (a) selection of "potential

site areas", (b) selection of "candidate sites" and (c) selection of two "final sites", one "primary" and one "secondary".

Selection of potential site areas, areas larger than 1 square mile, were based solely upon available data. That data included published information such as county geologic and groundwater investigative reports, soil survey reports and water well drilling reports submitted to the North Dakota State Water Commission (NDSWC) by private contractors. Topographic maps and county zoning maps were also used during the selection of potential site areas. A database was constructed to organize and group the resulting data.

The potential site areas selected represented areas of generally favorable geologic, geomorphic, and hydrogeologic conditions. More specifically, these were areas that possessed more than 30 feet of near-surface fine-textured materials; such as clay and silt.

Five candidate sites were selected from within the potential site areas. Selection of the five candidate sites was again based primarily on available data, but also included limited surficial investigations, such as soil borings, at each of the five sites. Topography was closely scrutinized during selection of the candidate sites, with more consideration being given to relatively flat areas. The relative position of the water table was a very important criteria and was approximated by color changes described in well completion reports filed with the NDSWC. Only sites with water tables more than 25 feet below the ground surface were considered.

Evaluation of the available data and the data acquired during the surficial investigations allowed for the five candidate sites to be

narrowed down to two final sites (Figure 2). Two of the five candidate sites were eliminated from consideration due to their relative topographic relief when compared to topography of the other sites. A third site was eliminated from consideration due to its location; it was adjacent to a residential area.

Each of the final two sites had their own advantages and disadvantages. Selection of two final sites was based on lithology, travel distance from Heskett Station and road restrictions, topography, and apparent depth to groundwater. Economics of site development, required zoning changes, land acquisition, transportation liability, and general permitability were all considered before selection of the primary site was made. Bore holes were drilled at each of the two final sites (maximum drilled depth: 120 feet) in an attempt to determine which site had more suitable geologic and geohydrologic settings for ash disposal.

The two final candidate sites had very similar geologic and geohydrologic characteristics. Both sites possessed very clay- and silt-rich surface and subsurface materials (each bore hole was geophysically and lithologically logged). Both sites also had relatively flat topography. After preliminary boring at each of the final two sites, it was determined that the water table at the Heskett site was shallower than the water table at site 6 (Table 2). However, volumetric calculations showed that, after considering the position of the water table at the Heskett site and allowing for an interval of at least 5 feet of fine-textured sediment between it and the pit bottom, sufficient volume would be available for ash disposal for a period of up to 30 years. MDU plans to use the disposal site for a period of approximately 30 years.

Although two final sites had very similar geologic and hydrologic characteristics, the Heskett site (Figure 2) was chosen as the primary disposal site because of its proximity to Heskett Station.

### Subsurface Investigation

The bore holes for this project were drilled by either a Portadrill 524 or a Denver-Gardner Heavy Duty 1000, both are truck-mounted forward rotary drills. Virtually all of the bore holes were drilled dry (without the addition of drilling fluids) and used only air to remove the cuttings. The holes were drilled dry where possible in order to prevent contamination of the groundwater. However, during the drilling of some of the wells water was added in the form of an air-mist. The introduction of water (from a hydrant near Heskett Station) was necessary when very moist horizons were encountered because the air alone was not sufficiently dense to remove the large wet agglomerations from the bore hole. Drilling conditions for each bore hole are indicated in Appendix A. Once the water table was encountered, sufficient water was available for cutting removal and the introduction of drilling water ceased. Samples were collected at 5-foot intervals or at depths of notable lithologic change and were used for well log descriptions and laboratory testing. Collected samples were bagged (cloth bag) and numbered according to well location.

A total of 27 observation wells were installed at the Heskett site study area during the course of this investigation. Twelve of these were water table monitoring wells and 15 were piezometers. The location of the various observation wells are shown in Figure 7. Additional

information on site hydrogeochemistry and hydrogeology were obtained from 9 wells that were installed during a previous groundwater investigation which was conducted immediately east of the current study area (Armstrong and Schmid, 1986).

The observation wells were generally installed in nests which consisted of 2 to 4 single wells. Each well in a given nest was screened at a different elevation. Nine separate piezometer nests were installed over the Heskett study area. The deepest well in each nest was geophysically and lithologically logged. A typical nest contained one water table monitoring well and two piezometers, each screened at a different elevation.

#### Monitoring Well Construction

The monitoring wells installed at the Heskett site were constructed of two-inch schedule 40 PVC pipe with screened lengths of either 4 or 20 feet. The screened intervals were constructed of factory slotted two-inch PVC pipe. Well completion reports are located in Appendix A. The 20-foot screened sections were installed to monitor the elevation of the water table and for water quality sampling. The 4 foot screened sections were installed to monitor hydraulic heads and for monitoring groundwater quality. A screen slot size of 1 X .020 inches was used for all of the wells installed at the Heskett site.

A filter sand pack was placed around the screened portion of each well after the pipe was lowered into the bore hole. The sand was packed using packing poles and packed to a height of two feet above the top of

the screened interval. Locally-derived washed quartz sand was used for the filter pack.

After the sand pack was complete, grout was slurried down the annulus between the bore hole and the PVC pipe to seal the remainder of the bore hole and prevent aquifer cross-contamination. The grout seal was continued to the land surface where a two-foot diameter grout pad was constructed around each monitoring well to prevent surface water infiltration. The monitoring wells were capped with threaded male PVC cap adaptors and given a unique well number. Figure 5a is a diagrammatic sketch of a typical piezometer installed at the Heskett site. Piezometers have pressure heads greater than zero and, consequently, water levels above the screened portion of the well. Figure 5b is a diagrammatic sketch of a typical watermonitoring well. Water table monitoring wells have pressure heads equal to tablezero and, therefore, water levels are within the screened interval and indicative of the actual position of the water table. Both well types were installed at the Heskett site.

The water level measuring reference point for the wells was arbitrarily chosen as the top of the PVC well pipe for reasons of convenience. North Central Consultants, Ltd., were contracted to survey, locate and determine elevations of each well. Well location, elevation and construction data are given in Appendix A.

#### Monitoring Well Development

Well development is the final stage of well installation. Often the natural hydraulic conductivity of the water producing strata is

appreciably changed during the drilling process. The purpose of developing the monitoring well is to restore the natural hydraulic conductivity which existed in the undisturbed sediments prior to drilling. Two methods of well development were used during the course of this project; they were backwashing and mechanical surging.

#### Backwashing

Backwashing causes the reversal of flow through the screened interval of the well which leads to the agitation of the sand filter pack and the removal of fine-grained material. The agitation introduced during this process causes a repacking of the sand grains in the filter pack from a cubic to a rhombic arrangement. The new packing arrangement prevents the fine grained materials from entering the well (Driscoll, 1986).

This form of well development was accomplished by removing water from the well by mechanical pumping. Some of the removed water was stored in a container which acted as a reservoir during the reversal stage. During the reversal stage, water from the pump tubing and the temporary reservoir was pumped back down into the well. It is this back flow surging of water that agitates and realigns the sand filter pack. After the wells had been backwashed they were purged by pumping at least 4 well volumes of water or pumped until dry, whichever occurred first. The final pumping of the well clears out all of the sediment which may have entered during the installation process.



## Mechanical Surging

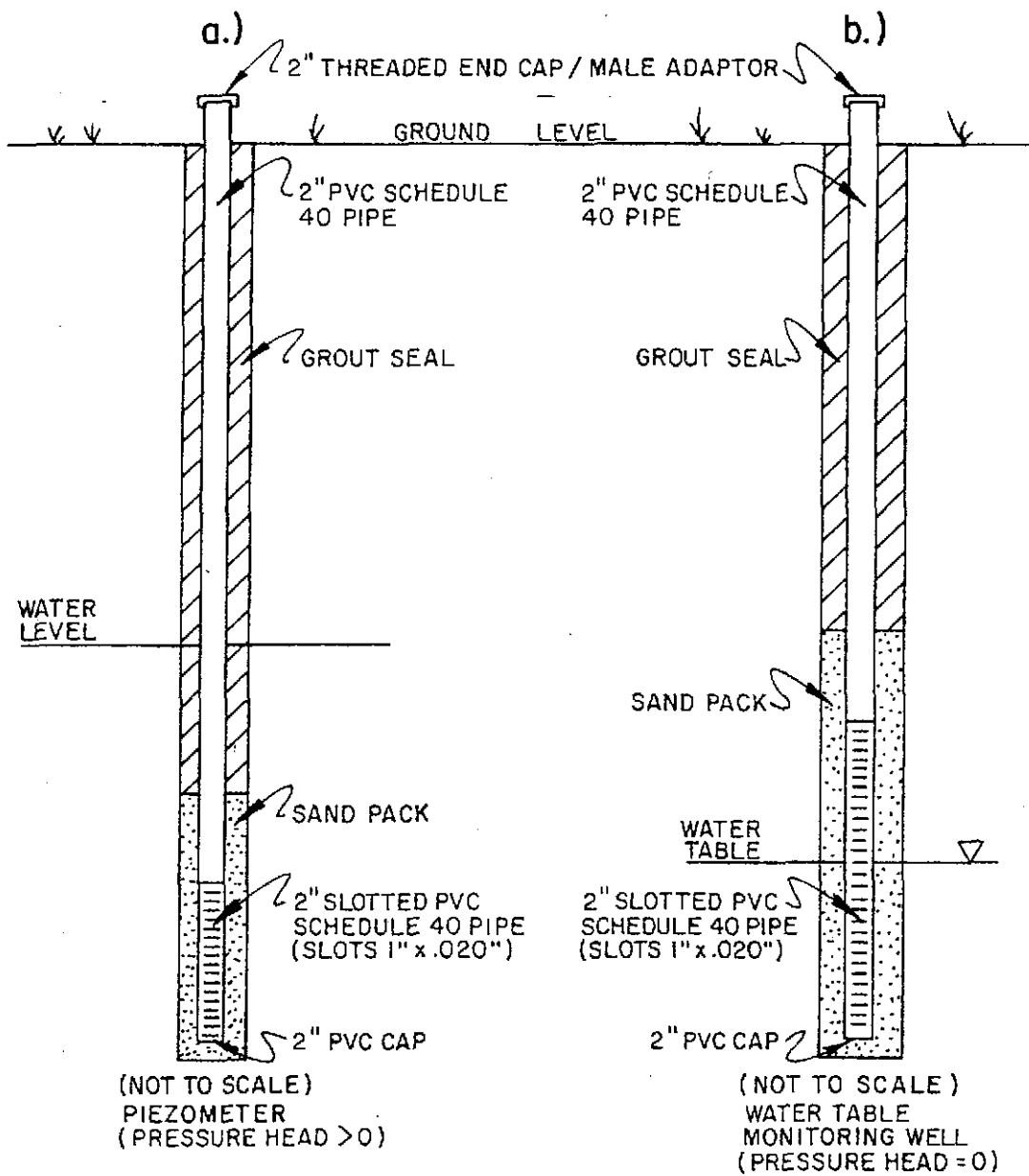
Mechanical surging and backwashing accomplish the same objective; removal of fine-grained materials and settling of the sand filter pack. During mechanical surging, water is forced out through the screen openings and then allowed to flow back in through the openings. This method of well development was accomplished using a ten-foot long, one-inch diameter bailer attached to a nylon rope. The bailer was dropped into the well, allowed to fill with water, and then lifted up above the water level. The well was allowed to recover before the bailer, full of water, was dropped back into the well. Water was forced out of the well through the screen when the full bailer was dropped back into the well. When the bailer was removed, water was once again free to enter the well through the screened portion.

After surging with the bailer was completed the well was purged by pumping at least 4 well volumes or pumped until dry, whichever occurred first. Each well at the Heskett site was developed using both methods, in other words, each well was developed twice. The wells were developed using both methods to assure complete restoration of the original hydraulic conductivity of the water producing strata and to assure a tight sand filter pack.

## Water Level Measurements

Water levels were recorded in biweekly intervals during the first three months of this project. After this period of time it was clear that the water levels over the entire site were quite static. Water

Figure 5. Diagrammatic sketch of typical monitoring wells installed at the Heskett site. Figure 5a represents a piezometer and 5b a water table monitoring well.



levels, since December 1986, have been recorded in monthly intervals. Water levels were measured with an electric-contact gauge tape manufactured by A. Ott CMBH Company of West Germany. With this instrument, recorded water levels (Appendix B) are accurate to the nearest centimetre (0.39 in). The reference point of all water level measurements is the top of the PVC well casing (with cap removed).

#### Groundwater Sampling Procedure

Each well was purged, prior to sampling, by removing at least 3 well volumes of standing water or pumped until the well went dry, which ever occurred first. The wells were purged with either a Keck Geophysical, Inc. mechanical two-inch submersible pump or a 1.25 inch hand bailer. If the well was pumped or bailed dry, sufficient time was allotted for recovery before the sample was collected. The pump used for purging is manufactured from stainless steel and teflon, both materials are very resistant to decomposition, which could affect water chemistries. All wells were purged and samples collected in accordance with the Environmental Protection Agency's publication 600/4-82-029, "Handbook for Sampling and Sample Preservation of Water and Waste Water" (U.S. EPA, 1982).

All of the groundwater samples analyzed from the Heskett site study area were collected by use of a hand bailer. Immediately after the samples were collected pH, specific conductance and temperature were determined and recorded.

Samples which were to be analyzed for major and trace elements were filtered in the field with a course 8 micron glass filter and then with

a fine 0.45 micron filter. Two samples were generally collected; 1000 mL for major ion analysis and 500 mL, acidified with nitric acid (5 mL), for trace element analysis. A third sample was collected from certain wells for oil, grease and phenol analyses. The oil, grease and phenol samples were not filtered and immediately after sampling were placed in a hexane rinsed glass jar with an aluminum foil cover. The well reference number, pH, conductivity, temperature and date of sampling were recorded on each sample bottle. The sample bottles were packed in ice and transported to UND for analysis.

## GEOLOGY

### Regional Setting

The Tertiary Cannonball Formation underlies the entire Heskett site study area. The Cannonball Formation is part of the Fort Union Group and was deposited during the Paleocene Epoch (between 55 and 65 million years ago). The Cannonball Formation is the only marine formation within the Fort Union Group. The lignite that is burned at Heskett Station originates from within the Sentinel Butte Formation, which is also part of the larger Fort Union Group. The Sentinel Butte Formation lies stratigraphically above the Cannonball Formation (Figure 6). The Cannonball Formation crops out over a large portion of eastern Morton County and forms the bluffs along the Missouri River north of Mandan near Heskett Station.

The Cannonball Formation is characterized by deposits of sand, silt and clay. Generally the beds within this formation are unconsolidated, and consequently, weather and erode rapidly. Some of the sand units are, however, partially cemented and as a result are resistant to erosion. The resistant units often form benches along eroded drainages (Carlson, 1983, p. 17). Cvancara (1976, p. 9) points out another characteristic of the Cannonball Formation; lack of persistent litho-stratigraphic units or beds. The units are often truncated because most bedding within this formation is lenticular.

The Cretaceous and Tertiary rocks in this portion of North Dakota generally dip toward the center of the Williston Basin. Reported dips of the Cannonball Formation in the Bismarck-Mandan area are generally

less than  $1^{\circ}$  and trend toward the northwest. However, local irregularities in dip direction and magnitude are common in the Cannonball Formation. These minor variations are caused by small synclines and anticlines which are superimposed on the larger structure of the basin (Kume and Hansen, 1965, p.46). The small anomalies may be responsible for local irregularities in groundwater flow direction and magnitude.

The Cannonball Formation interfingers with its continental equivalent, the Ludlow Formation. The two formations are thus contemporary, with deposition of the Cannonball occurring in a marine environment and deposition of the Ludlow occurring in a fresh water environment.

Figure 6. Partial stratigraphic column showing position of the Cannonball Formation within the Fort Union Group.



ERA	SYSTEM	FORMATION OR GROUP		THICKNESS (FEET)	LITHOLOGY
CENOZOIC	QUATERNARY	ALLUVIUM		0-30	SILT, SAND AND GRAVEL
		COLE HARBOR		0-300	TILL, GRAVEL AND SAND
	TERTIARY				
		FORT UNION GROUP	GOLDEN VALLEY	0-60	SILT, CLAY AND SANDSTONE
			SENTINEL BUTTE	0-700	SILT, CLAY, SAND AND LIGNITE
			BULLION CREEK	0-500	SILT, CLAY, SAND AND LIGNITE
			SLOPE	0-60	SILT, CLAY, SAND AND LIGNITE
			CANNONBALL	0-300	SILT, CLAY AND SAND
			LUDLOW	0-200	SILT, CLAY, SAND AND LIGNITE

## Geology of the Heskett Disposal Site

The proposed Heskett disposal site would be constructed completely within the Cannonball Formation. Lithologic and geophysical logs of the wells drilled at this site indicated that at least the upper 100 feet of the site is within the Cannonball Formation. The Ludlow formation may appear in subsurface of the Heskett site study area below an elevation of 1605 feet above mean sea level (MSL). Only the deepest bore holes drilled penetrated to this elevation and geophysical logs from these wells do not show any indication of the contact between the two formations. Therefore, it appears that all of the bore holes drilled at the Heskett site remained exclusively within the Cannonball Formation.

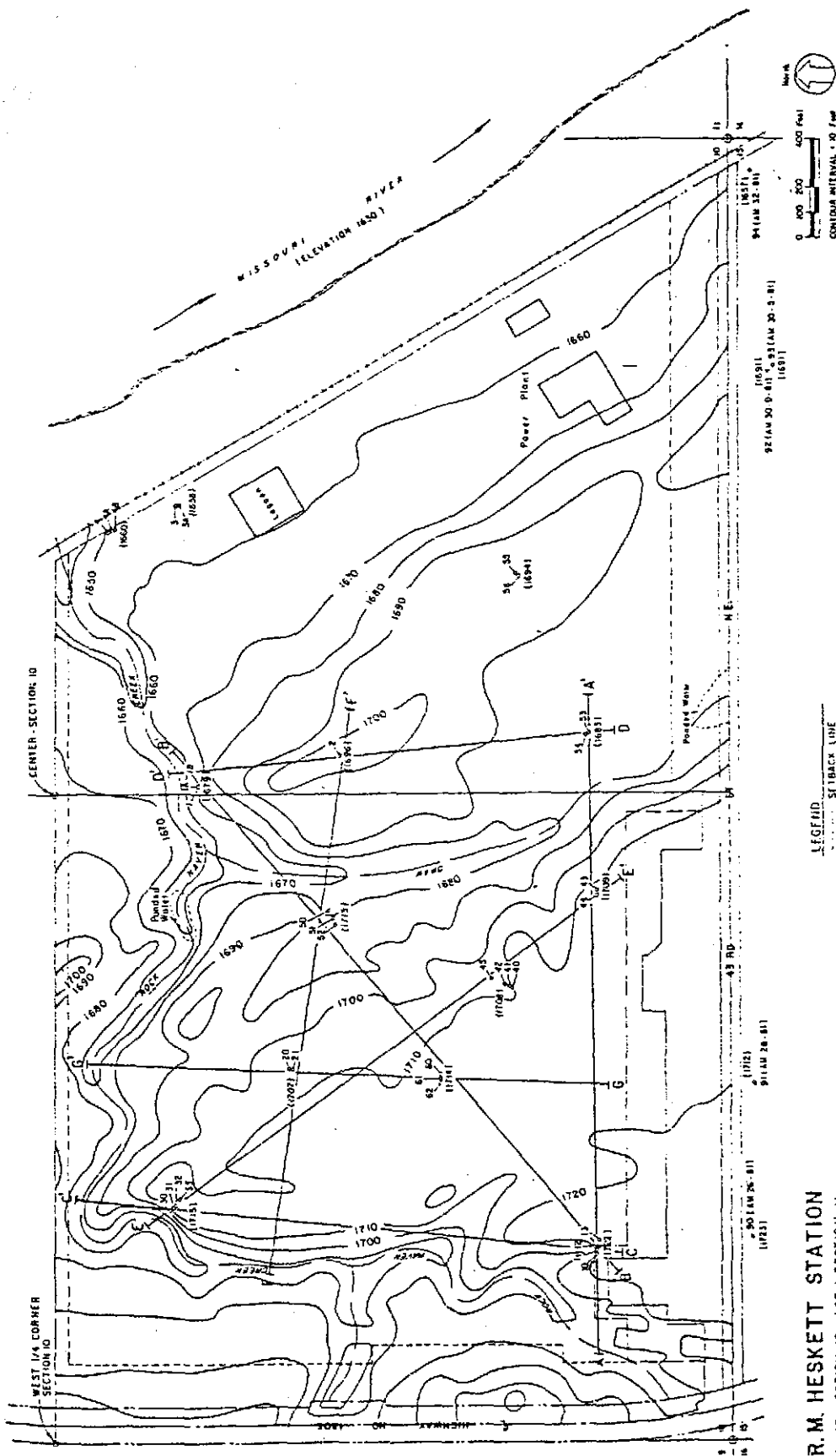
A series of eight geohydrologic cross-sections of the proposed Heskett disposal site are provided in Figures 8-15. Each cross-section includes topography (exaggerated 10 times), dominant lithologies, observation well locations, potentiometric levels and water table position. A topographic reference map, with well locations and cross-section locations, is provided in Figure 7. The area which is being proposed for the actual disposal pit is located in the western half of Figure 7.

The Cannonball Formation, within the Heskett study area, consists of unconsolidated silt and clay with lesser amounts of very fine-to medium-grained sand (lithologic log, Appendix C). Generally, the sand is found interspersed in a matrix of silt and clay; however, it sometimes occurs as distinct lenses which range in width from 0.5 inches to 1 foot. The thin sand lenses are not horizontally persistent. Small gypsum crystals occur throughout the upper 30 feet of the Cannonball

Formation in this area. The gypsum crystals are presumed to be the result of diagenetic processes which occur above the water table during alternate wetting and drying cycles (Groenewold et al., 1983) The dominant lithology of the site, as illustrated in Figures 8-15, is silt which commonly occurs in a clay-rich matrix. Above an elevation of 1695 feet MSL, the clayey-silt is generally brownish-tan in color while below this elevation the color changes to steel-gray. This upper portion is oxidized with grain coatings and mottling of iron-oxides, while the lower portion is reduced. The reduced/oxidized boundary corresponds with the color change described above and it also corresponds with the elevation of the water table.

The only indurated unit encounter within the Heskett study area occurs at a depth, over the proposed disposal area, greater than 65 feet. This unit is a siltstone and occurs between the elevations of 1625 feet and 1635 feet MSL (Figure 8). This is also the most laterally continuous and persistent unit encountered at the Heskett site. Generally, the units within the Cannonball Formation are not laterally continuous. This lack of continuous beds or units is directly related to the environment in which the formation was deposited. The sands of this formation were probably deposited along beaches and in deltas of ancient seas, while the silts and clays were deposited in deeper more quiet water, or possibly in shallow quiet water. The oceans were very dynamic during this period with fluctuating sea levels and fluctuating sediment loads being carried into them by rivers. This constant variability prevented one depositional regime from gaining dominance over the others. The continual change, which was common in the eustatic seas

Figure 7. Topographic map of the proposed Heskett ash disposal site with cross-section and observation well locations.



**R. M. HESKETT STATION**  
S 1/2 SECTION 10, LOT 1 SECTION 11  
TOWNSHIP 139 NORTH - RANGE 81 WEST  
MORTON COUNTY, NORTH DAKOTA

Figure 8. Geohydrographic cross-section A - A'.  
See Figure 7 for location of cross-section.



Figure 9. Geohydrographic cross-section B - B'.  
See Figure 7 for location of cross-section.



B  
(SOUTHWEST)

B'  
(NORTHEAST)

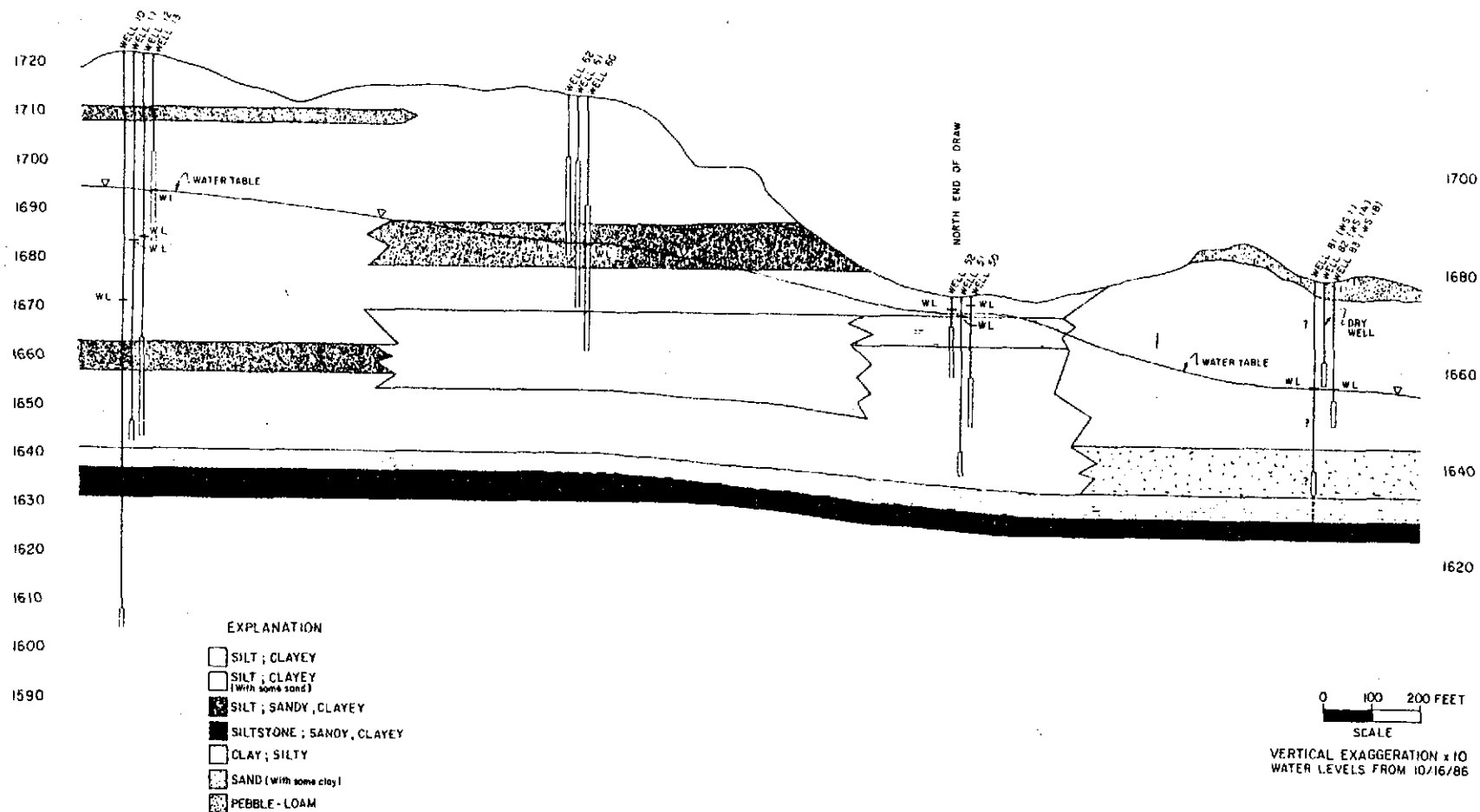


Figure 10. Geohydrographic cross-section C - C'.  
See Figure 7 for location of cross-section.

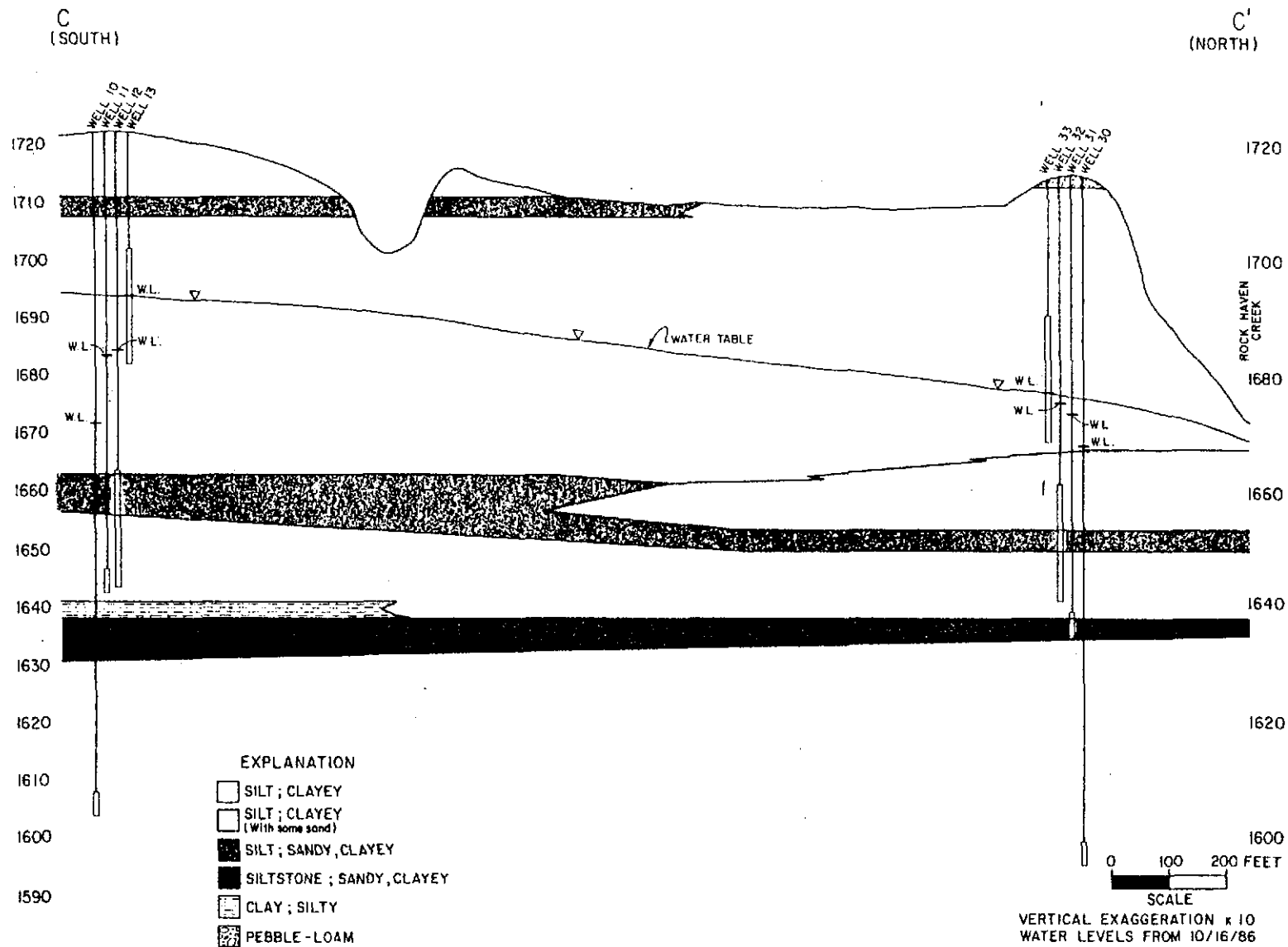


Figure 11. Geohydrographic cross-section D - D'.  
See Figure 7 for location of cross-section.

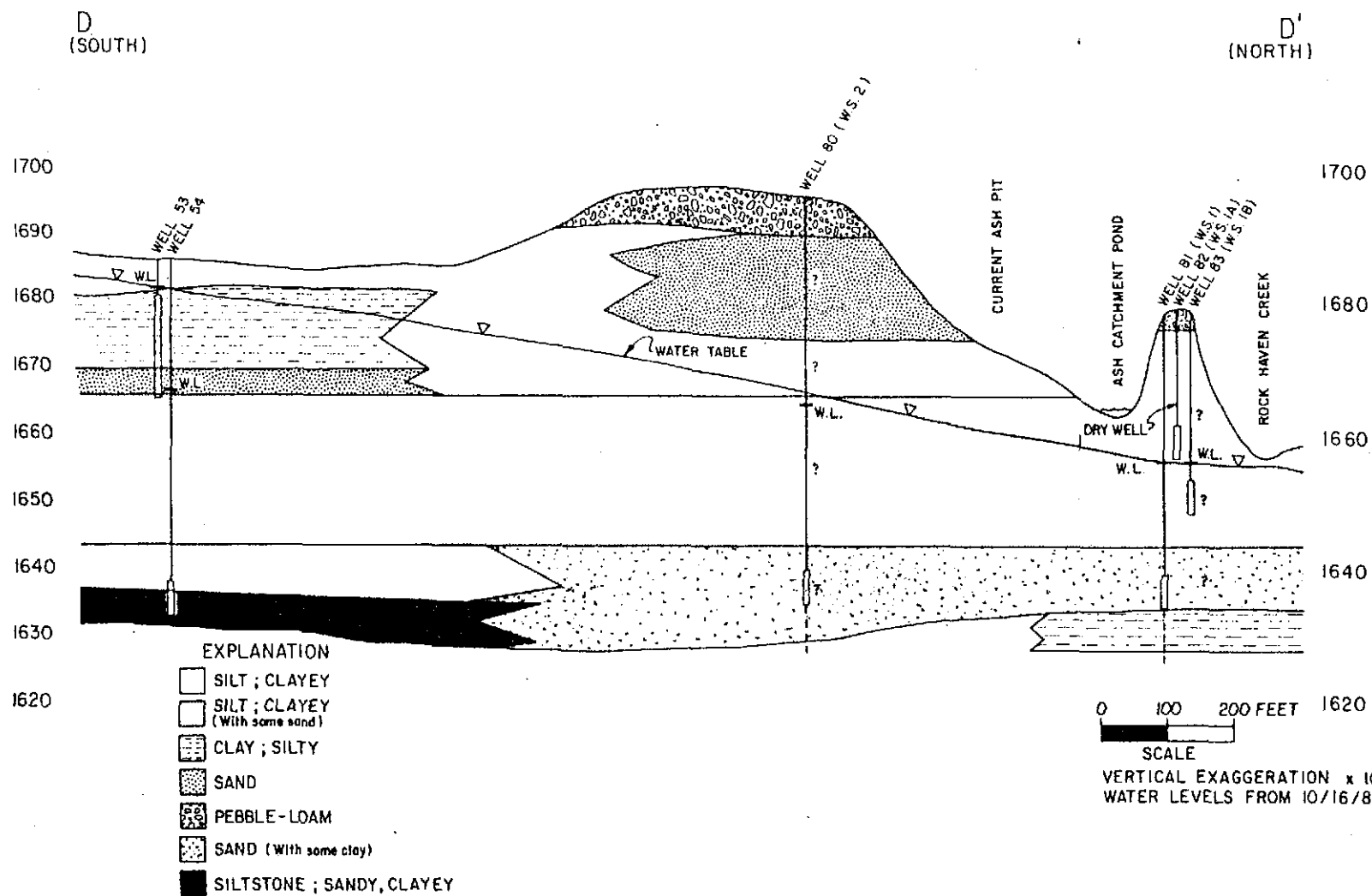
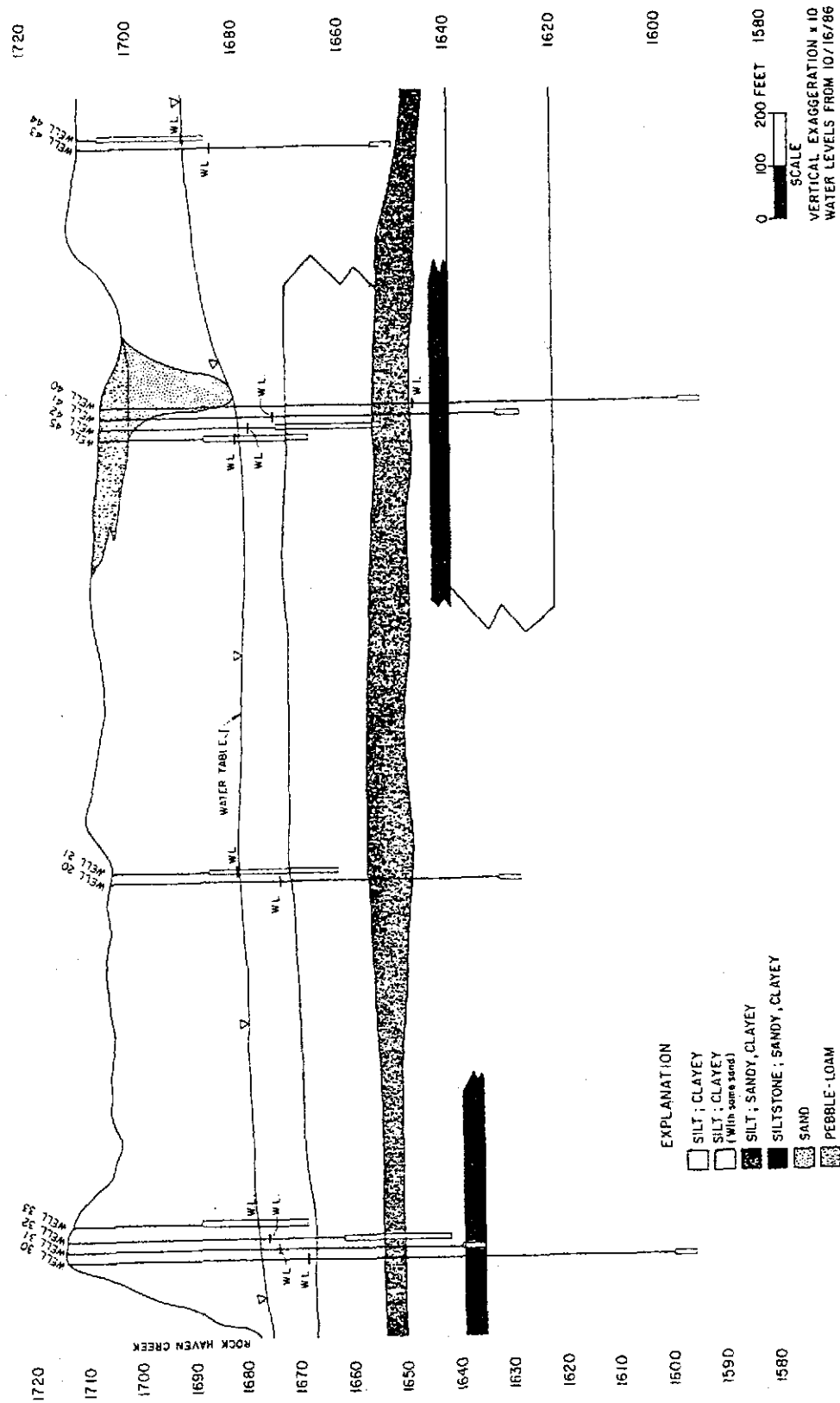
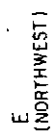


Figure 12. Geohydrographic cross-section E - E'.  
See Figure 7 for location of cross-section.

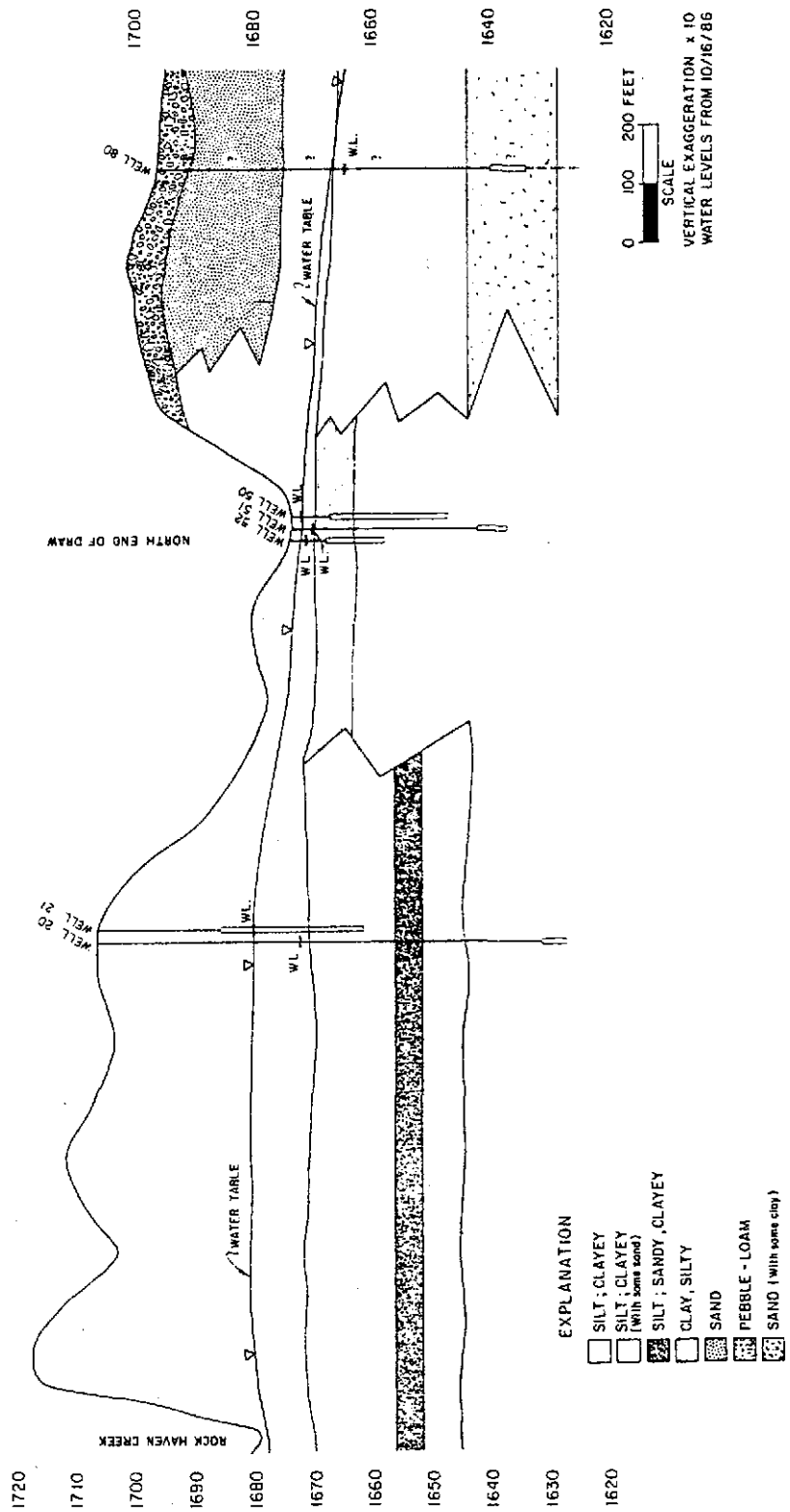


**EXPLANATION**

- ☐ SILT ; CLAYEY  
☐ SILT ; CLAYEY  
 ( With some sand)  
☒ SILT ; SANDY, CLAYEY  
☐ SILTSTONE ; SANDY, CLAYEY  
☐ SAND  
☐ PEBBLE-LOAM

Figure 13. Geohydrographic cross-section F - F'.  
See Figure 7 for location of cross-section.





**EXPLANATION**

- ☐ SILT ; CLAYEY  
☐ SILT ; CLAYEY  
 ( With some sand )  
☒ SILT ; SANDY, CLAYEY  
☐ CLAY, SILTY  
☒ SAND  
☒ PEBBLE - LOAM  
☒ SAND ( with some clay )

Figure 14. Geohydrographic cross-section G - G'.  
See Figure 7 for location of cross-section.

G  
(SOUTH)

G'  
(NORTH)

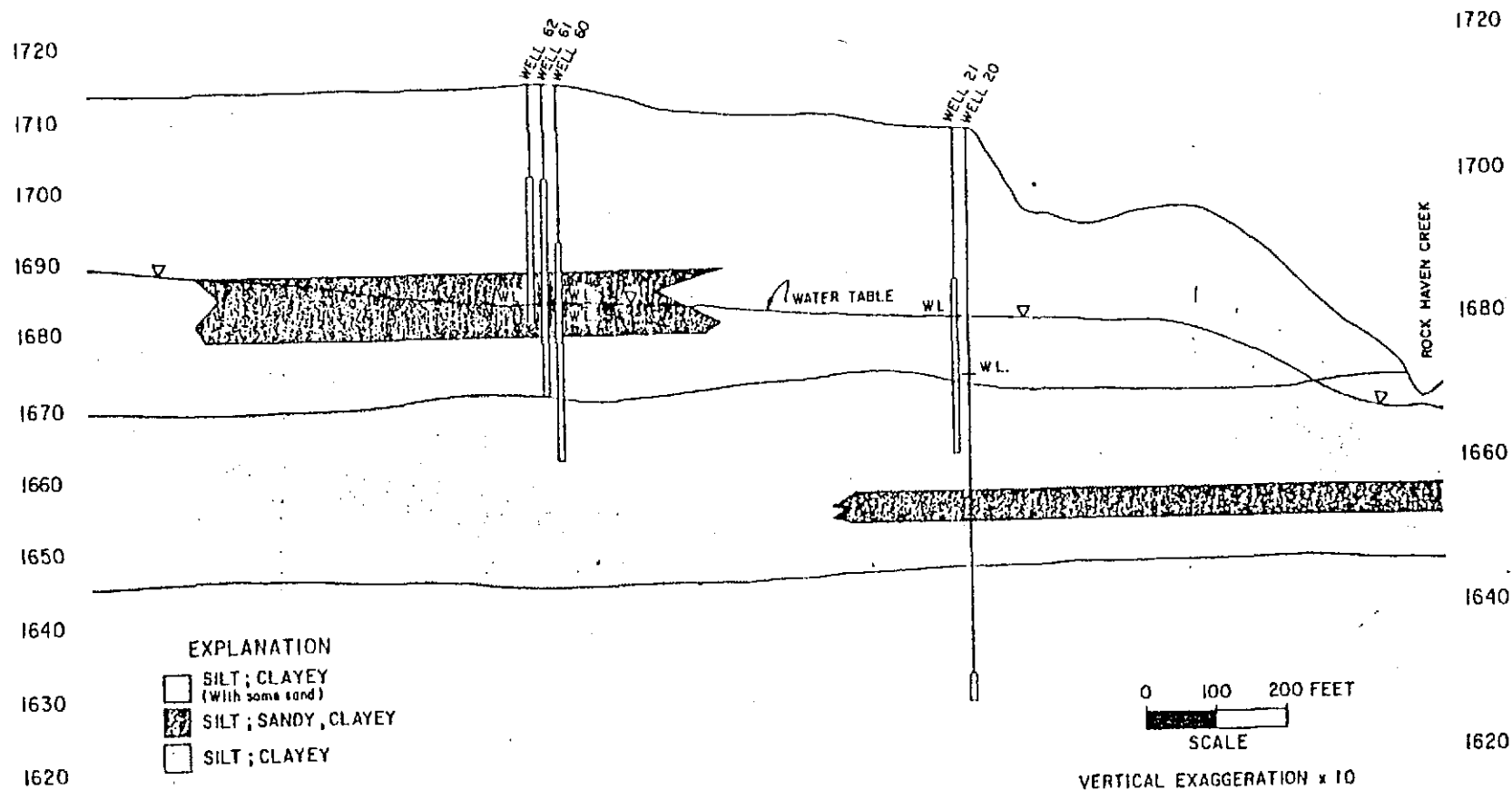
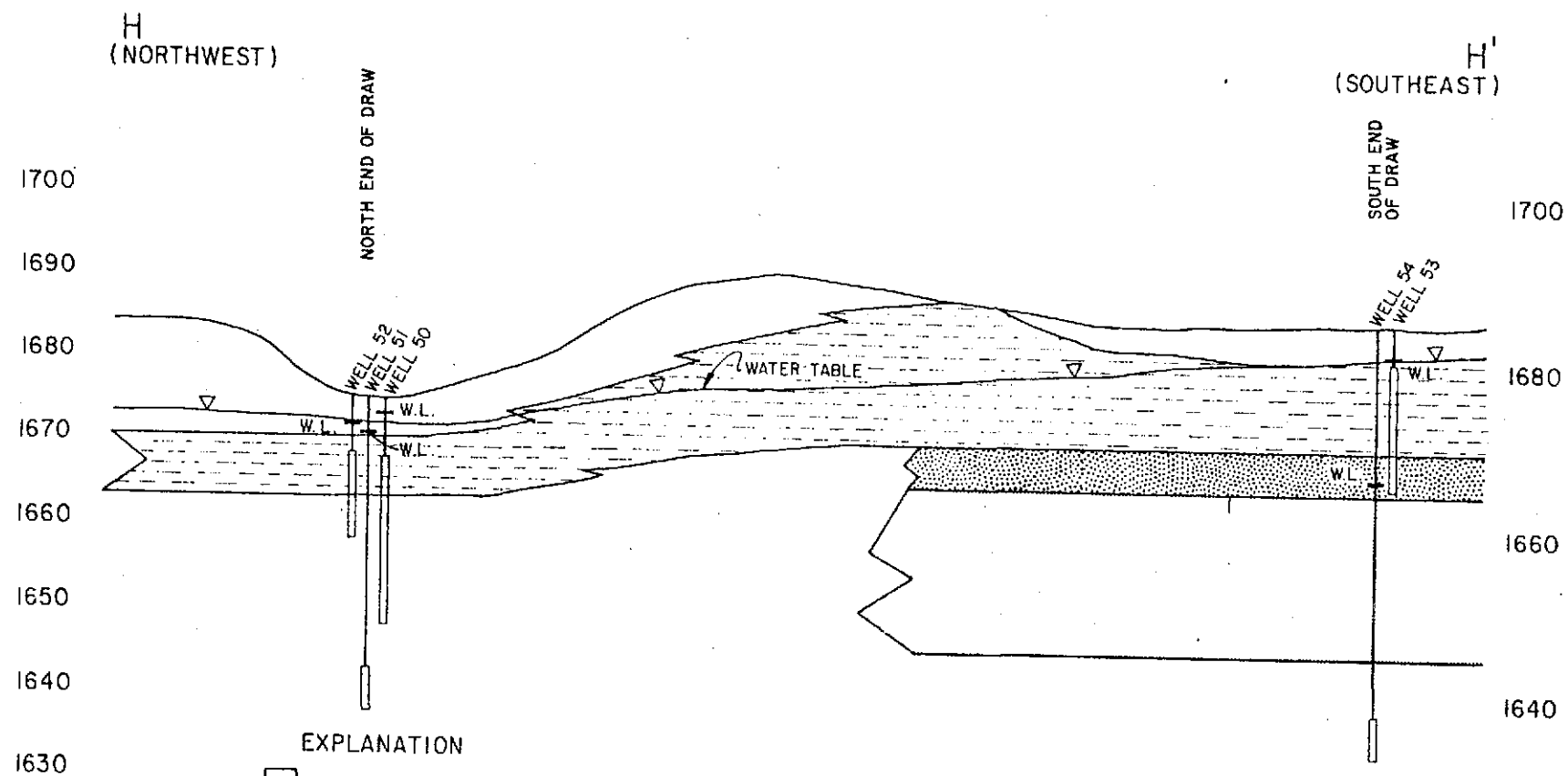


Figure 15. Geohydrographic cross-section H - H'.  
See Figure 7 for location of cross-section.



- EXPLANATION
- SILT ; CLAYEY
  - SILT ; CLAYEY  
(With some sand)
  - CLAY ; SILTY
  - SAND

0 100 200 FEET  
SCALE  
VERTICAL EXAGGERATION x10  
WATER LEVELS FROM 10/16/86

of the Tertiary, accounts for the lack of consistent units within the Cannonball Formation.

A thin veneer of till is present in small patches throughout the Heskett study area. This till, along with all glacial material in North Dakota, has been grouped within the Coleharbor Formation (Bluemle, 1971, p. 16). Generally the till of the Heskett study area is very thin, less than 2 feet, and is in the form of a pebble-loam. This till is apparent in the geohydrologic cross-section B-B' (Figure 9) in the vicinity of wells 40-43. Other evidence of glaciation includes the presence of several large boulders, less than 3 feet in diameter, which were derived from the Canadian Shield.

The glacial sediments indicate that glacial ice covered the study area during the Pleistocene Epoch. Horizontal sheet fracturing may have developed within the surficial bedrock formations, including the Cannonball Formation, as this glacial ice ablated. The fracturing of these sediments would be considered secondary porosity and this "unloading" phenomenon could be responsible for the relatively large flow volumes encountered within the silts and clays at the Heskett site study area.

The soil across the proposed Heskett ash disposal area is generally well developed. Edwards and Ableiter (1936) classified the soil across the upland area of the site as silt-loam, in particular; Hall series, silt-loam. This is a very productive soil and care should be taken to preserve the soil in a stock pile for surface reclamation as the disposal cells become filled with ash. The soil is very silty with abundant clay and minor amounts of fine-grained sand. Internal soil

drainage is good and surface drainage is sufficient (Edwards and Ableiter, 1936).

The soil within the area of the proposed ash disposal pit ranges of 0 to 2 feet in thickness. Over most of the area the soil is approximately 1 foot thick. The upper 6 to 8 inches are very dark with abundant organic matter. Below 8 inches the soil becomes lighter in color. All of the soil at the Heskett site is calcareous and effervesces freely with dilute hydrochloric acid.

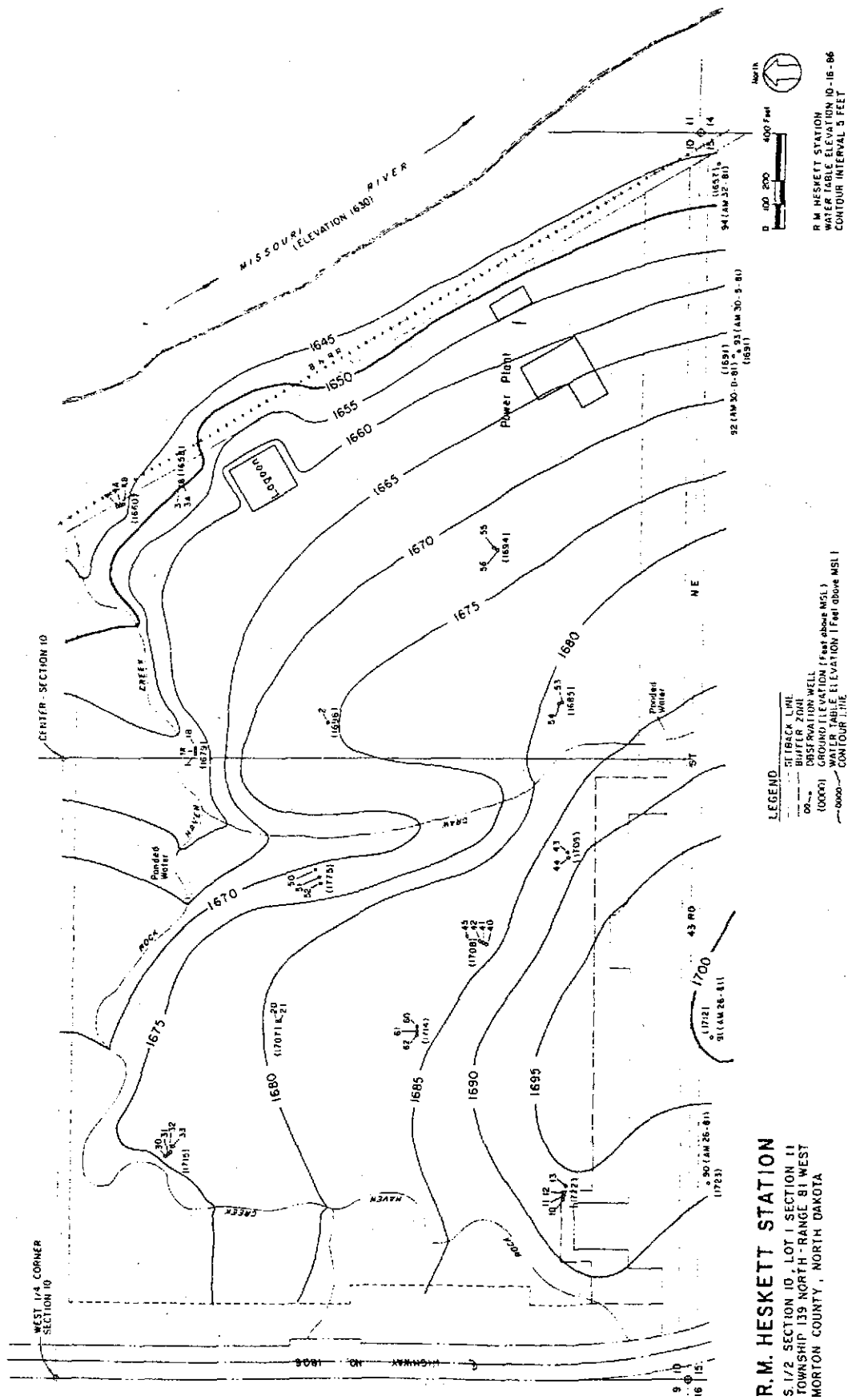
## GEOHYDROLOGY

### Groundwater Flow

In general, the shallow groundwater at the Heskett study area is flowing towards the northeast (Figure 16). However, local variations do exist and these, for the most part, are caused by the heterogeneous nature of the lithologies of the Cannonball Formation and by the undulating surface topography of the site. The surface topography has the most profound affect on groundwater flow and, in general, the elevation of the water table mimics the surface topography. Figure 16, a water table elevation contour map of the Heskett site, shows the relationship between surface topography and groundwater flow (compare to topographic map, Figure 7). Water elevations for this contour map were recorded October 16, 1986. Due to relatively static water levels observed during the course of this project, the elevation of the water table (Figure 16) is representative until significant changes are recorded in the observation wells; to date (May, 1987) there have been only minor changes. Water levels of all of the Heskett site wells are given in Appendix B. The flow of groundwater (Figure 16) is perpendicular to the contours drawn on the map and in the down-slope direction. Groundwater flows from areas of higher hydraulic head to areas of lower hydraulic head. From Figure 16 it can be concluded that the groundwater flow within the area proposed for ash disposal (the western half of Figure 16) is toward the north-northeast. As the groundwater approaches the Rock Haven Creek it begins to take a more



Figure 16. Water table contour map of the Heskett  
site study area .



easterly path and generally follows the down-cut gradient of this creek into the Missouri River.

The groundwater flow within the area of the small draw, which extends from the south-central border of section 10 northward to its intersection with the Rock Haven Creek, is nearly directly north (Figure 16). Groundwater flow in this area is strongly influenced by the surficial topography, which dips toward the north in this draw. Surface water, from holding ponds on the south, is discharged into this draw. Running and ponded water are visible on the north side (MDU property) of the section road which divides the Amoco property on the south from the MDU property on the north. The ponds located on the Amoco Refinery property may be leaking and causing artificial recharge to the shallow aquifer in this area. The constant recharge may have caused the local water table to rise somewhat above its natural level and may be responsible for the static water levels observed during the fall and winter of 1986-87.

Hydrographs of the various selected Heskett site wells are given in Figures 17-20. In this region of North Dakota there is often a drop in the elevation of the water table during the winter months due to the lack of recharge during this time (Groenewold, et al., 1979 and Groenewold, et al., 1983). Hydrographs of Heskett wells 11, 12, 31 and 32 show an increase in water level elevation during the winter months (Figures 17 and 18, respectively). This increased elevation may reflect artificial recharge from the south or natural recharge due to the mild 1986-87 winter. Without further information from observation wells located to the south, on Amoco property, it is impossible to determine which type of recharge is responsible for the static to slightly

increasing winter water levels. Hydrographs of wells 10 and 40, Figures 17 and 19 respectively, demonstrate the effects of drilling on water levels. The two wells were installed on August 13, 1986. The water levels show a significant decrease in elevation during the first three weeks of recording. After the first three weeks they attain relatively static levels. Apparently the high water levels recorded on August 15, 1986 were induced by the addition of water during drilling from either the overlaying units or from the drilling process itself. Well construction data indicate that some water (air-mist) was introduced into these wells during drilling (Appendix A). The conductivity of the units wells 10 and 40 are screened in is so low that it took approximately 3 weeks to attain static and natural levels. The hydrograph of wells 60-62 (Figure 20) show a relatively static water table with time. All three of these wells are water table monitoring wells.

Potentiometric data from the proposed disposal site indicate that the groundwater is flowing downward. The downward component of flow is depicted in Figures 8-15 which are geohydrologic cross-sections showing the potentiometric levels of various Heskett site wells. These data indicate that there is no upward component of groundwater flow in the upper 100 feet of the site. Thus, it can be concluded that water will not be entering the proposed disposal pit from beneath the site.

#### Hydraulic Conductivity

The Heskett site was selected as the "primary" disposal site for three reasons: 1) the presence of silt- and clay-rich lithologies,

2) position of the water table and 3) site location. Our task was to locate a site that would be characterized by low-permeability sediments, preferably having a permeability equal to or less than  $10^{-7}$  cm/sec ( $1.96 \times 10^{-7}$  ft/sec). With this coefficient of permeability the groundwater, or leachate, would migrate at a rate of only 3.15 cm/year (1.24 in/year) under a head differential of North Dakota. Six of the samples were analyzed during a previous groundwater investigation at Heskett Station; these samples were collected less than 900 feet from the eastern border of the proposed disposal site. The previous investigation was completed by Water Supply Incorporated of Bismarck, North Dakota. All six of the samples from their investigation were cored samples and, therefore, are representative of in situ hydraulic conductivities. One sample (well 60) from the current investigation by MMRI was tested for its coefficient of permeability. However, this sample 1.5 metres (5.0 feet). Figure 21 shows the effect hydraulic conductivity has on the movement of groundwater. Flow is vertical in low permeability materials such as clay, and horizontal in high permeability materials such as sand and gravel. The strong downward component of flow is also shown in this figure as indicated by the arrows.

A total of seven samples from in and near the proposed ash disposal site were lab tested to determine hydraulic conductivity. The conductivities were determined by Twin City Testing Corporation of Bismarck, was bagged from cuttings during drilling and, therefore, is not representative of in situ conditions. Table 2 is a summary the results of the hydraulic conductivity testing for the samples described above. The abbreviation "WS" refers to wells installed and sampled

during the previous groundwater investigation at Heskett Station which was conducted by Water Supply Incorporated. Figure 7 shows the location of the observation wells from which the samples were collected. Table 2 also shows the cation exchange capacity for the intervals analyzed.

Figure 17. Hydrograph of wells 10, 11, 12 and 13.  
See Figure 16 for well locations.

# HYDROGRAPH

Wells 10, 11, 12 and 13

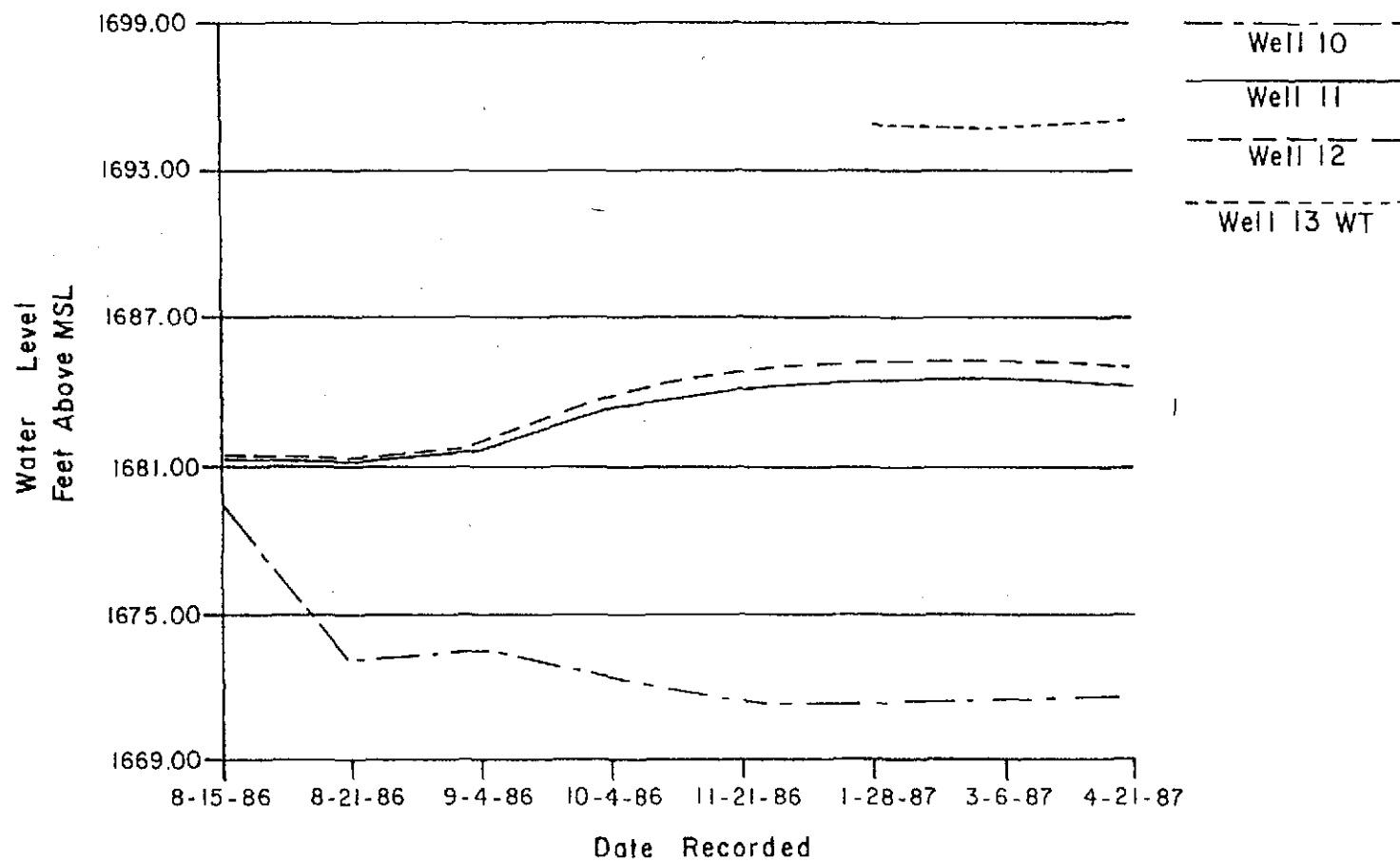




Figure 18. Hydrograph of wells 30, 31 32 and 33.  
See Figure 16 for well locations.

# HYDROGRAPH

Wells 30, 31, 32 and 33

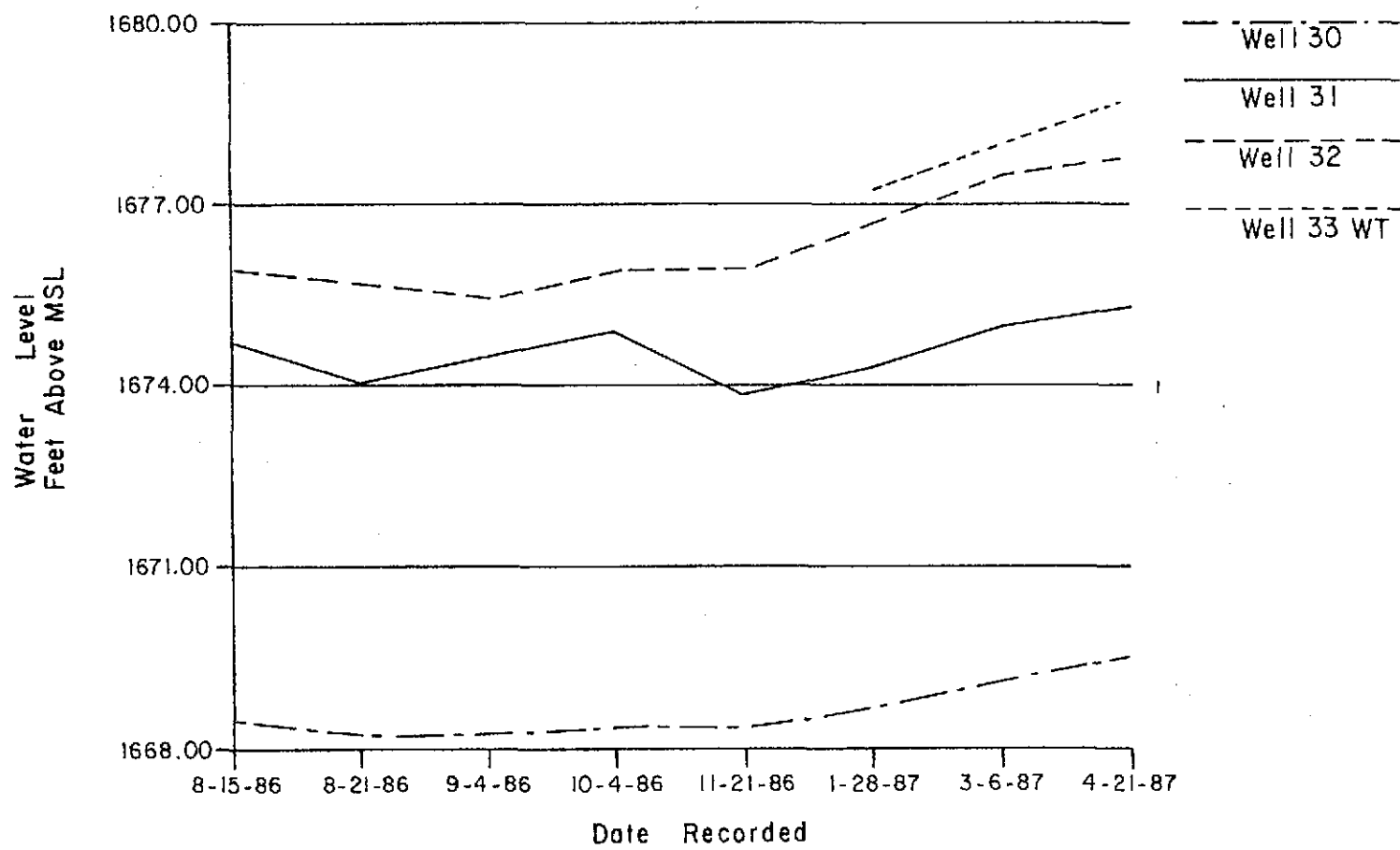


Figure 19. Hydrograph of wells 40, 41, 42 and 45.  
See Figure 16 for well locations.

# HYDROGRAPH

Wells 40, 41, 42 and 45

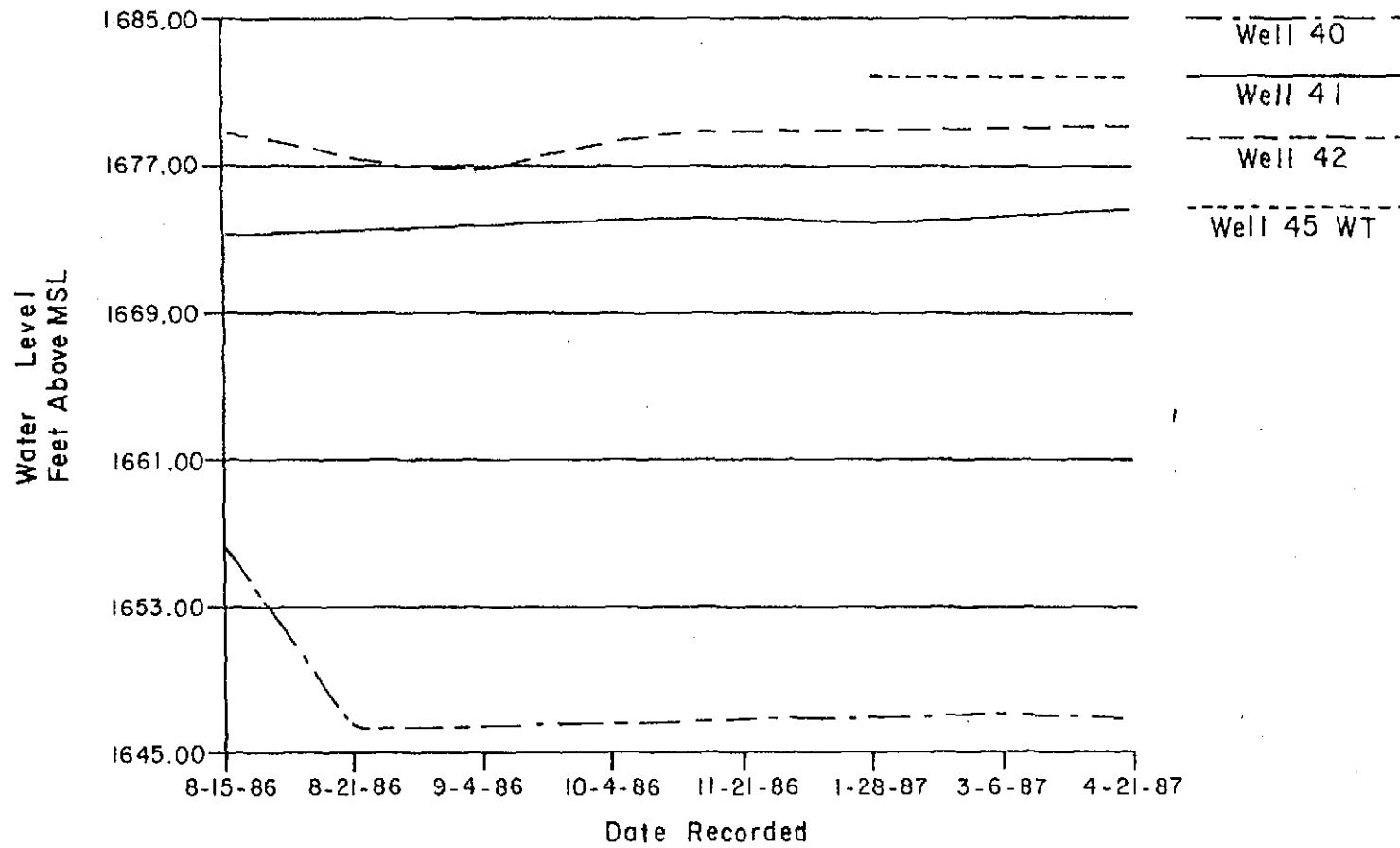


Figure 20. Hydrograph of wells 60, 61 and 62.  
See Figure 16 for well locations.

# HYDROGRAPH

Wells 60, 61 and 62

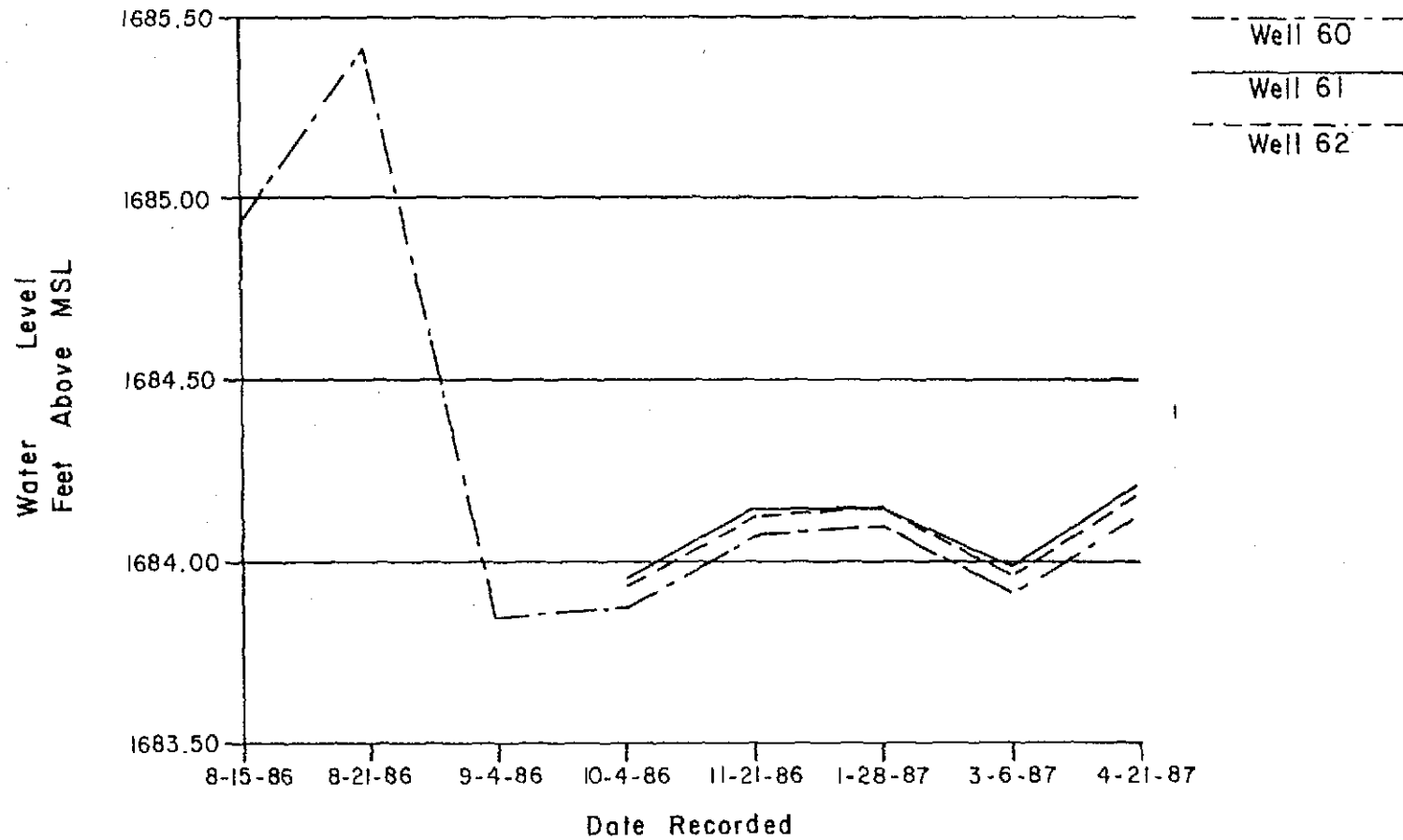
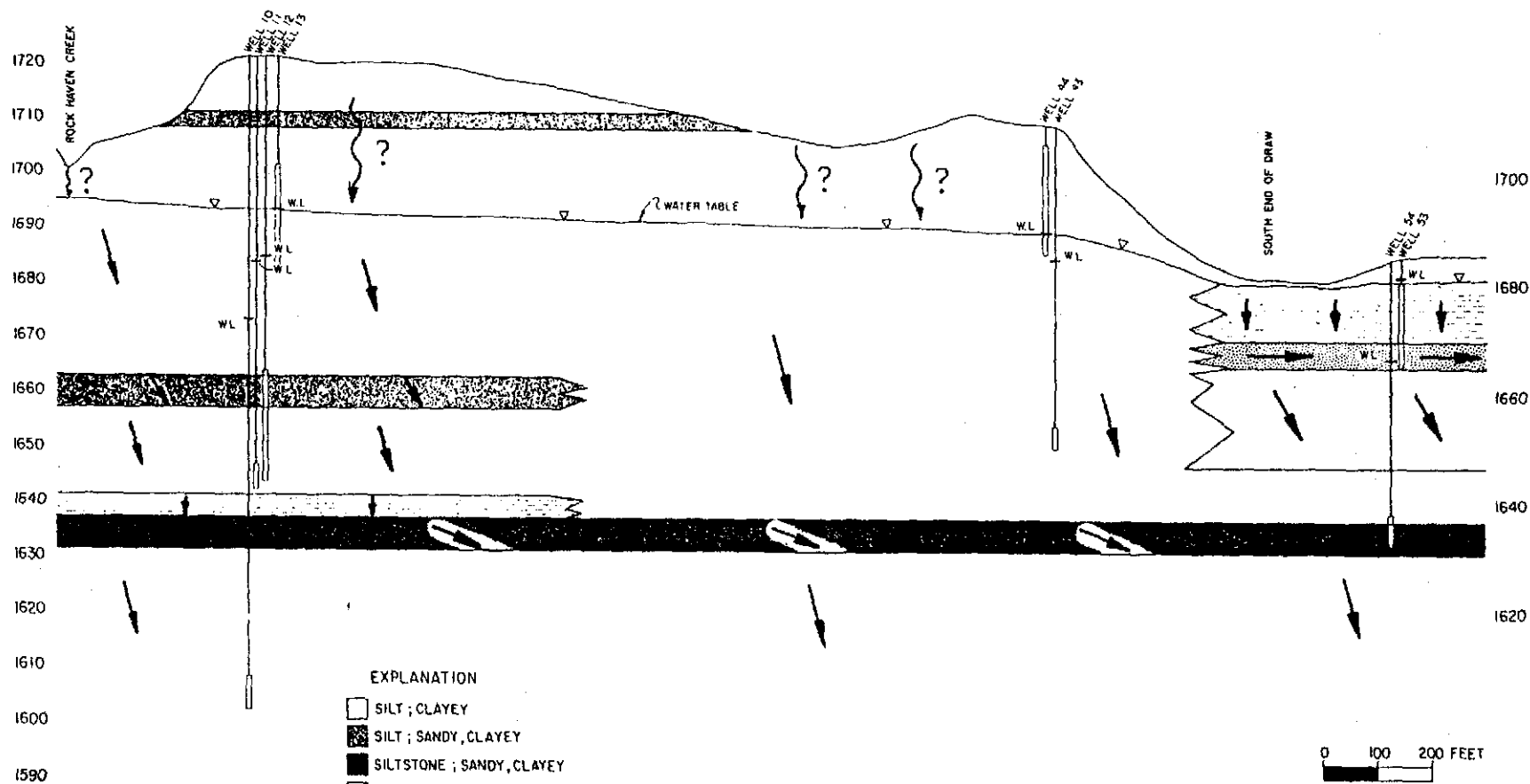


Figure 21. Hydrostratigraphic cross-section (A-A')  
showing groundwater flow at the site.  
Groundwater tends to flow more vertically in  
low permeability materials and horizontally in  
high permeability materials such as sand.

A  
(WEST)

A'  
(EAST)



VERTICAL EXAGGERATION x 10  
WATER LEVELS FROM 10/16/86



TABLE 2

Hydraulic Conductivity and Cation Exchange Capacities  
(Well numbers correspond with well numbers on Figure 7)

Well Number	60	80 (W.S. 2)	80 (W.S. 2)
Sample Depth (ft)	20-40	29-30	61-62
Type of Sample	Bag	Core	Core
Permeability			
K @ 20 °C (cm/sec)	$2.0 \times 10^{-7}$	$2.7 \times 10^{-9}$	$3.6 \times 10^{-8}$
K @ 20 °C (ft/min)	$4.0 \times 10^{-7}$	$5.4 \times 10^{-9}$	$7.1 \times 10^{-8}$
Cation Exchange Cap. (meq/100 grams)	-----	92.2	12.0
Well Number	81 (W.S. 1)	81 (W.S. 1)	81 (W.S. 1)
Sample Depth (ft)	20-21	25-26	30-31
Type of Sample	Core	Core	Core
Permeability			
K @ 20 °C (cm/sec)	$2.6 \times 10^{-8}$	$1.5 \times 10^{-8}$	$1.7 \times 10^{-8}$
K @ 20 °C (ft/min)	$5.2 \times 10^{-8}$	$2.9 \times 10^{-8}$	$3.4 \times 10^{-8}$
Cation Exchange Cap. (meq/100 grams)	71.8	12.3	74.2

Data attained from lab permeability testing must be analyzed in its context. These data are representative of only a very small portion of the subsurface geologic media; specifically, at the point of core-sampling. For example, cored-samples analyzed for permeability may miss subsurface areas of fracturing thereby giving misrepresentative overall permeabilities. Additionally, samples are often modified, in terms of hydraulic conductivity, during well drilling and sample collection. These data are, however, valuable for estimating flow rates through interstices in the subsurface geologic media. This type of permeability testing is especially valuable in situations where the in situ sediments are going to be modified by compaction. In this case, lab testing will give an accurate indication of the sediment permeability after compaction.

Single-well response tests from selected Heskett site wells (wells 11, 20, 31, 41 and 43) have greater permeabilities than the falling-head lab permeabilities of wells screened in the same sediments. As mentioned above, lab tests only consider a small portion of the subsurface materials. The slug tests performed on the Heskett wells give permeabilities over a 4-foot interval. Results of the single-well response tests show that wells 11 and 31 have the lowest permeabilities of the wells tested with values of  $K = 3.78 \times 10^{-5}$  cm/sec and  $K = 2.84 \times 10^{-5}$  cm/sec, respectively. Higher conductivities were encountered in wells 20, 41 and 43 with values of  $K = 6.57 \times 10^{-4}$  cm/sec,  $K = 4.12 \times 10^{-4}$  cm/sec and  $K = 5.07 \times 10^{-4}$  cm/sec, respectively. The discrepancy between lab and field permeabilities could be due to minor subsurface fracturing which was not encountered or preserved in the cored samples.

## HYDROGEOCHEMISTRY

### Groundwater Quality

The groundwater quality of the Heskett study area is quite variable. Tabulations of water analyses are given in Appendix D. The background chemical composition of the groundwater will be used as the baseline composition for comparison once ash disposal begins. With a strong background database, assessment of disposal practices will be easier and more accurate. Analysis of samples collected from wells 10-70 were completed by the MMRRRI's Fuels Analysis Laboratory at the University of North Dakota in accordance with EPA publication 600/4-79-020, "Methods for Chemical Analysis of Water and Wastes" (U.S. EPA, 1979). Drinking water standards are provided in Table 3 (Freeze and Cherry, 1979, p. 386) and can be used as a reference for water quality judgements.

The background quality of the shallow (less than 120 feet below the land surface) groundwater at the proposed Heskett disposal site is very poor. The groundwater, without the addition of a purification system, is unfit for human and, in many areas, livestock consumption. Most of the domestic wells in this area tap either the Hell Creek or the Fox Hills aquifers, both of which underlie the Cannonball Formation. The quality of the water from both of these formations is far superior to that of the Cannonball.

TABLE 3  
Drinking Water Standards

Constituent	Recommended Concentration Limit <sup>1</sup>	
Total Dissolved Solids	(mg/L)	500
Sulfate (SO <sub>4</sub> )	(mg/L)	250
Chloride (Cl)	(mg/L)	250
Nitrate (NO <sub>3</sub> )	(mg/L)	45
Iron (Fe)	(mg/L)	0.3
Manganese (Mn)	(mg/L)	0.05
Copper (Cu)	(mg/L)	1.0
Zinc (Zn)	(mg/L)	5.0
Boron (B)	(mg/L)	1.0
Hydrogen Sulfide (H <sub>2</sub> S)	(mg/L)	0.05
Maximum Permissible Concentration <sup>2</sup>		
Arsenic (As)	(mg/L)	0.05
Antimony (Sb)	(mg/L)	0.01
Barium (Ba)	(mg/L)	1.0
Cadmium (Cd)	(mg/L)	0.01
Chromium (Cr)	(mg/L)	0.05
Lead (Pb)	(mg/L)	0.050
Mercury (Hg)	(mg/L)	0.002
Selenium (Se)	(mg/L)	0.01
Silver (Ag)	(mg/L)	0.050
Fluoride (F)	(mg/L)	1.4-2.41 <sup>3</sup>
Organics:		
Cyanide	(mg/L)	0.05
Phenol	(mg/L)	0.001
Synthetic Detergents	(mg/L)	0.5

<sup>1</sup>Recommended concentration limits for these constituents are mainly to provide esthetic and taste characteristics.

<sup>2</sup>Maximum permissible limits are set according to health criteria.

<sup>3</sup>Limit depends on average air temperature of the region; fluoride is toxic at about 5-10 mg/L if water is consumed over a long period of time.

Even though the shallow groundwater at the Heskett site is of poor quality it is of the same quality as other shallow wells within the Cannonball Formation (Ackerman, 1977 and 1980). Large quantities of salts and soluble mineral phases were trapped and deposited along with the sediments of this formation. The salts and soluble phases dissociate as undersaturated interstitial groundwater flows through the formation. The ultimate quality of the water depends on the solubility of the geologic media and saturation condition of the groundwater which flows through it. Specific constituents of the shallow groundwater at the Heskett site, as well as in other wells within the Cannonball Formation, are high or very high relative to water in other aquifers in the area. This indicates that there are abundant soluble mineral phases present within the Cannonball Formation.

Specific conductance, temperature and pH of the wells sampled at the Heskett site are within the range of what is expected from the Cannonball Formation. The chemical analyses (Appendix D) indicate that water within wells 60 and 70 have the highest specific conductance. Well 70 is located upgradient from possible industrial influences of either MDU or Amoco, and thus, can be considered as representative of background groundwater quality. The pH of all Heskett site wells sampled ranged from 6.7 to 8.6.

Total dissolved solids (TDS) is a good general indicator of groundwater quality and degree of mineralization. TDS exceeds primary drinking water standards, which are 500 mg/L, in all of the Heskett site

wells, which indicates that the shallow groundwater in this area is highly mineralized. TDS ranged from 1,286 mg/L in well 30 to 14,917 mg/L in well 60 (Appendix D). The levels are very high and are at the upper end of concentrations common to this formation. Wells screened within the Cannonball Formation commonly have TDS concentrations ranging from 1,000 to 3,000 mg/L (Ackerman, 1980).

Sodium levels of wells 10, 12, 55 and 70 are very high, well above concentrations common to the Cannonball Formation. Wells finished within the Cannonball Formation typically have sodium concentrations ranging from 500 mg/L to 1000 mg/L (Ackerman, 1977 and 1980). Sodium, TDS and other parameters such as sulfate indicate that extremely saline pockets of groundwater exist at the southwestern (near wells 70, 10-13, and 60-62) and east-central (near wells 55 and 56) borders of the Heskett study area (Figure 7). Sulfate concentrations of the water within wells 44, 55, 60 and 70 are higher than those of any other wells at this site. The highest sulfate concentration, 11,632 mg/L, was recorded in well 60 on November 10, 1986.

Both magnesium and calcium concentrations are relatively high and quite variable over the Heskett site study area. Well 44 contains the highest levels of these two constituents with 648 mg/L of calcium and 1,322 mg/L of magnesium. These are the primary ions responsible for "hard water" and with levels as high as these the water at the Heskett site would be considered very hard. Actual hardness values (expressed as  $\text{CaCO}_3$ ) range from 222 mg/L in well 30 to 7,040 mg/L in well 60.

Chloride, potassium, iron and fluoride concentrations are generally within the expected range of concentrations for wells finished within the Cannonball Formation. However, potassium is slightly elevated in wells 44 and 60 where it reaches concentrations of 51 mg/L and 41 mg/L, respectively.

Nitrate concentrations are very erratic over the Heskett site. Wells 55 and 60 contain the highest nitrate levels with 170 mg/L and 154 mg/L, respectively. The drinking water standard for nitrate ( $\text{NO}_3^-$ ) is 45 mg/L. The nitrate concentrations in wells 50, 52, 55 and 60 indicate contamination. A sewage drainfield was identified near the south-central border of the proposed disposal site in the vicinity of wells 43 and 44. The source of the sewage is the four furthest east homes along the north side of the section road leading to Heskett Station. This point source could be responsible for some of the elevated nitrate concentrations observed, but it seems unlikely that this is the main source of contamination.

Selenium concentrations exceed drinking water standards of .010 mg/L in wells 42, 44, 50, 52, 54, 55 and 60. Wells 55 and 60 have the highest concentrations with .368 mg/L and .195 mg/L, respectively. Selenium is a common naturally- occurring element in sediments, especially in shale and clay (Freeze and Cherry, 1979, p. 421). However, the levels observed in these two wells are above levels common to groundwater systems which contain shale and dissolved selenium and are well above concentrations observed in groundwater from the Cannonball Formation. The maximum selenium concentration observed in

the Cannonball Formation was .004 mg/L (Ackerman, 1977); nearly 100 times less concentrated than levels observed by MMRI in well 60.

Molybdenum, which is not presently included in the primary drinking water standards, is present at detectable levels wells 10, 54 and 70. Other wells at the site generally show molybdenum near or below detection limits. Water Supply Incorporated (WS), in their previous groundwater investigation concerning the current Heskett ash pile, noted concentrations of molybdenum in well 84 similar to those observed in this study in wells 10, 54 and 70 (Appendix D). Well 84 (WS 4) was a well noted for increasing molybdenum levels with the greatest concentration reaching .030 mg/L on March 12, 1985 (Armstrong and Schmid, 1986). As of September 11, 1986 the molybdenum levels in this well had dropped below detection limits. With the addition of background monitoring wells upgradient from the current ash pile, we were able to demonstrate that the elevated molybdenum concentrations observed near the ash pile were not a function of leachate migration. The concentrations of molybdenum in well 84 (W.S.) were within the background chemical range of groundwater at the Heskett site. In other words, the elevated molybdenum concentrations noted by WS were not caused by the migration of leachate from the existing ash pile.

Other trace elements are generally below detectable limits and will not be discussed here. Complete analyses of Heskett background groundwater samples are given in Appendix D.

Figures 22 and 23 summarize the quality of the Heskett site groundwater. Wells 12, 44, 55, 60 and 70 contain water with the greatest



quantities of total dissolved constituents. The key species in this system are  $\text{Ca}^{2+}$ ,  $\text{HCO}_3^-$ ,  $\text{Na}^+$  and  $\text{SO}_4^{2-}$ . The highest quality water is found within wells 30-33, which are located in the furthest northwest corner of the proposed disposal site. The poorest quality water is found within wells 55, 60 and 70. Wells 50, 52, 55 and 60 contain elevated nitrate concentrations.

In summary, the groundwater at the proposed Heskett coal-ash disposal site is of very poor quality and is highly mineralized. The chemical characteristics of the shallow groundwater are primarily due to naturally occurring processes at the site rather than from man-made impacts.

#### Groundwater Chemical Evolution

The chemical composition of groundwater in a given region is a direct reflection of the types of geologic media through which it has moved. Groenewold et al. (1983) have proposed a conceptual model for the geochemical evolution of groundwater in central and western North Dakota. The following discussion summarizes some critical geochemical reactions and processes believed to be occurring at the proposed Heskett disposal site and follows the framework proposed by Groenewold and others (1983). The most important control in the evolution of groundwater is pH which is directly related to the hydrogen ion ( $\text{H}^+$ ) concentration. The typical groundwater in shallow units (upper 300 feet) in central and western North Dakota acquires  $\text{H}^+$  mainly from two

Figure 22. Summary of major ions present in the groundwater at the proposed Heskett ash disposal site. Samples were collected from selected wells on September 10, 1986.

# HESKETT WATER ANALYSES

Summary of Major Ions

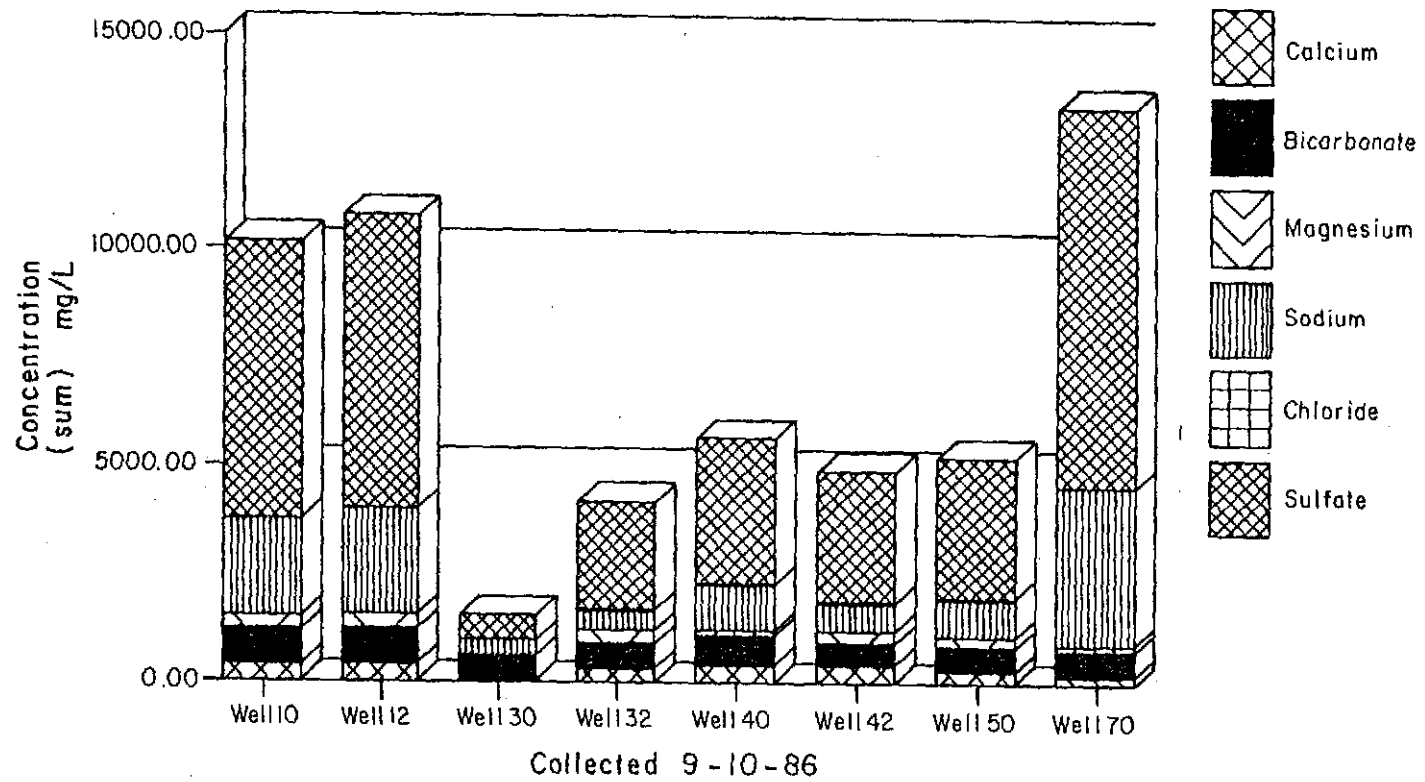
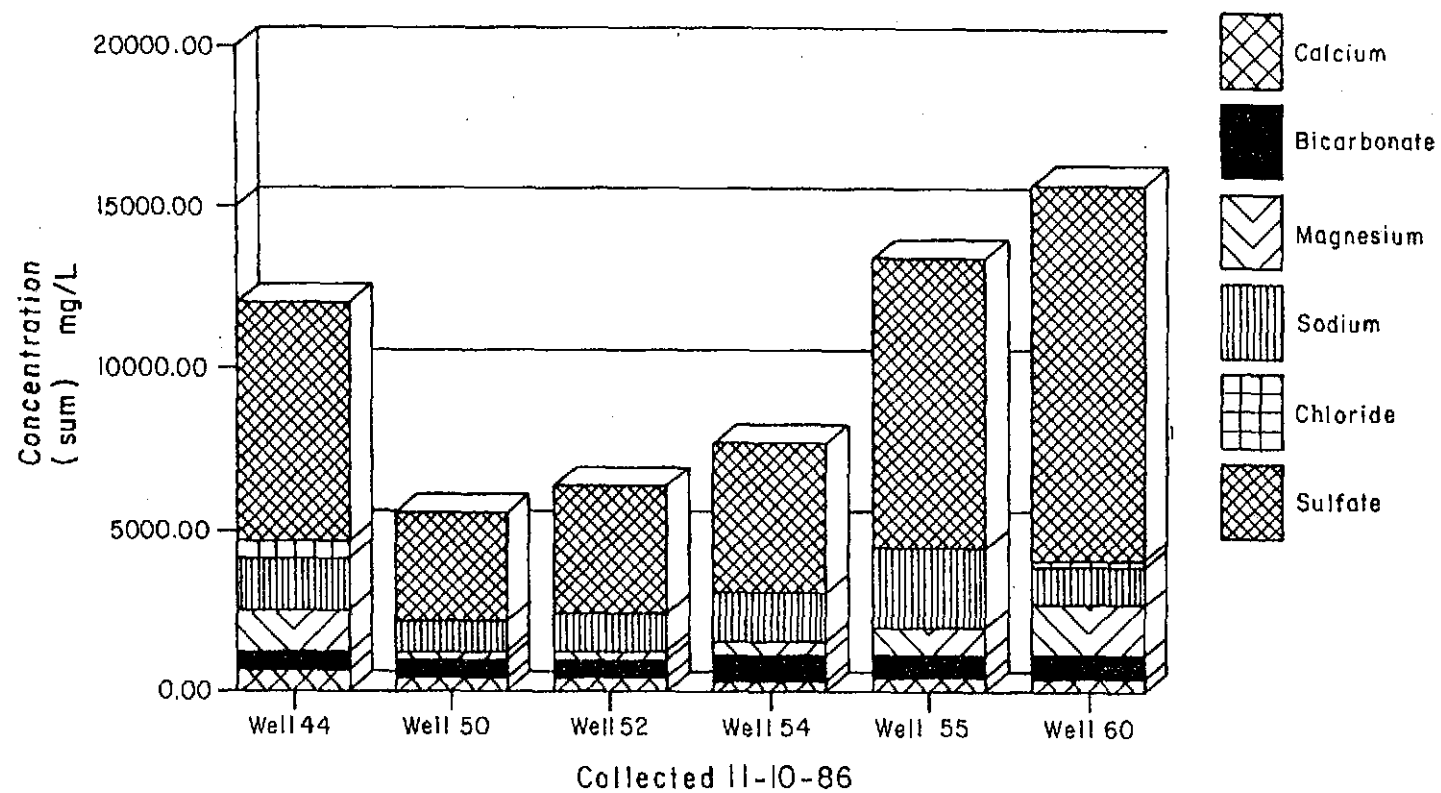


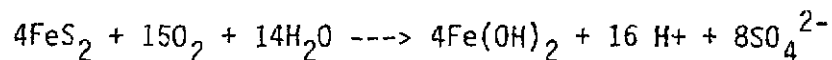
Figure 23. Summary of major ions present in the groundwater at the proposed Heskett ash disposal site. Samples were collected from selected wells on November 11, 1986.

# HESKETT WATER ANALYSES

## Summary of Major Ions

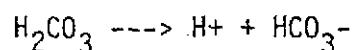


sources (1) the oxidation of organic matter and (2) the oxidation of sulfide minerals such as pyrite. Pyrite oxidation can be expressed by the following reaction:

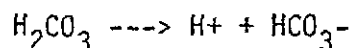


Pyrite oxidation is believed to be the dominant  $\text{H}^+$  source in the central and western North Dakota setting. In addition to being a strong acid producing reaction, it also yields abundant sulfate ions ( $\text{SO}_4^{2-}$ ).

Once the hydrogen ions are in solution they are free to react with carbon dioxide ( $\text{CO}_2$ ) produced during oxidation of organic matter, this leads to the formation of carbonic acid ( $\text{H}_2\text{CO}_3$ ). Carbonic acid, in turn, dissociates to form  $\text{H}^+$  and bicarbonate ( $\text{HCO}_3^-$ ) by the following reaction:



Bicarbonate will dissociate further because  $\text{H}_2\text{CO}_3$  is an acid:

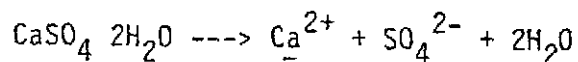


Bicarbonate is the most abundant form of carbon within the common pH range (6-9) of natural waters (Drever, 1982).

With carbonic acid and free hydrogen ions in solution, calcite ( $\text{CaCO}_3$ ) and dolomite ( $\text{Ca,Mg}(\text{CO}_3)_2$ ) will dissociate producing  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and  $\text{HCO}_3^-$ . The Cannonball Formation contains abundant calcite and dolomite. The presence of both of these mineral phases is confirmed by

the abundance of calcium and magnesium ions present in the shallow groundwater at the study site (Appendix D).

Gypsum dissolution is a secondary source of  $\text{Ca}^{2+}$ . Dissolution of gypsum is represented by the following reaction:



This reaction, along with pyrite oxidation, are the key processes by which sulfate is produced. Sulfate is the major constituent of the groundwater at the proposed Heskett ash disposal site and is probably the result of gypsum dissolution. The highest concentration of sulfate at the Heskett site (11,632 mg/L) occurs in well 60. The above reaction is reversible and is dependent upon the state of saturation of the groundwater with respect to gypsum. Dissolution of gypsum occurs during meteoric precipitation events, and chemical precipitation occurs after rainfall and snow melt events as water is concentrated through evapotranspiration (Moran et al., 1976 and Groenewold et al., 1983). Alternate wetting and drying cycles are the key geochemical process responsible for accumulation of crystalline gypsum in and beneath the soil zone in central and western North Dakota. The upper 30 feet of the proposed Heskett disposal site contains abundant small (less than .3 inch X .25 inch) gypsum crystals. The presence of the crystals indicates that precipitation/dissolution reactions are occurring at the site and, therefore, play a key role in groundwater evolution with respect to  $\text{Ca}^{2+}$  and  $\text{SO}_4^{2-}$ .

The partial pressure of carbon dioxide ( $\text{PCO}_2$ ) is another important control on chemical evolution of groundwater in these settings.  $\text{PCO}_2$  is responsible for the generation of carbonic acid which is the main acid that dissolves carbonate minerals.  $\text{CO}_2$  is replenished in open systems and this leads to high concentrations of  $\text{HCO}_3^-$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  through dissociation of calcite and dolomite. Closed systems are controlled by the initial pH and initial  $\text{PCO}_2$  of the system and, therefore, approach equilibrium faster than open systems. Consequently, closed systems have lower concentrations of  $\text{HCO}_3^-$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  than do open systems.

As discussed above, the dominant lithology of the Cannonball Formation is silt in a clay-rich matrix with minor amounts of sand; this type of lithology carries the generic name of "mudstone". Sodium montmorillonite (Na-montmorillonite) is the dominant clay mineral in the Cannonball Formation along with minor amounts of illite and kaolinite (Fenner, 1974, p. 17). Groenewold et al. (1983) found that Na-montmorillonite was the dominant clay mineral in the coal-bearing Tertiary sediments of western North Dakota. Though mineralogic studies were not carried out on the Tertiary sediments at the Heskett site, it seems reasonable to assume, by association, that these sediments are similar to those described by Fenner (1974), Groenewold et al. (1979) and Groenewold et al. (1983). Fenner (1974, p. 33) analyzed a clay sample obtained from the Cannonball Formation less than 20 miles west of the proposed Heskett disposal site and found it to consist of 85 percent montmorillonitic clay.



The clay mineralogy is very important when considering ion exchange and its relationship to groundwater evolution because ion exchange is driven by preferential adsorption of one ion over another. For example,  $\text{Ca}^{2+}$  is adsorbed in preference to  $\text{Na}^+$  or  $\text{Mg}^{2+}$ .  $\text{Mg}^{2+}$  is, in turn, preferentially adsorbed over  $\text{Na}^+$  (Freeze and Cherry, 1979). Because ion exchange removes ions from solution, it plays a critical role in controlling the solubility of mineral phases such as gypsum. The smectite group, of which Na montmorillonite is a member, has the greatest cation exchange capacity (CEC) of any clay mineral group; typically in the range of 80-150 milliequivalents per 100 grams (meq/100 g) of dry clay (Drever, 1982, p. 82).

With dissociation of carbonate and evaporite minerals and oxidation of sulfide minerals,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and  $\text{SO}_4^{2-}$  will be incorporated as characteristic ions of the infiltrating groundwater. If Na-montmorillonite is present the water will be modified further by the exchange of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  for  $\text{Na}^+$  in the clay structure. Two sodium ions will be removed from the clay structure for each calcium or magnesium ion adsorbed. As  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  are adsorbed, a solution that was once saturated with respect to gypsum and/or other carbonate minerals will become undersaturated, allowing for further dissociation of these mineral phases. Ion exchange then becomes the key process controlling the solubility and, therefore, the dissolution of gypsum. Cation exchange causes groundwater to attain a high sodium characteristic with relatively low concentrations of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ . The removal of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  also allows for continuous accumulation of  $\text{HCO}_3^-$  and  $\text{SO}_4^{2-}$  from calcite and gypsum dissociation. It is this

process that is responsible for extremely high  $\text{SO}_4^{2-}$  concentrations observed in the shallow groundwater at the Heskett site.

Cation exchange is an active geochemical process, according to the above model, at the proposed Heskett disposal site. Dominant groundwater ions include:  $\text{SO}_4^{2-}$ ,  $\text{HCO}_3^-$ ,  $\text{Na}^+$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ .

The model, in a qualitative manner, predicts and explains the relative abundance of the major constituents in the groundwater at the Heskett site.

## ASH CHARACTERIZATION

In disposal site design, understanding of the physical, mineralogical and chemical characteristics of the waste material is essential in predicting the reactivity of that waste in a particular disposal environment.

The ash to be disposed of at the Heskett site has been characterized using x-ray diffraction, scanning electron microscopy (SEM), electron microprobe analysis (EMPA) and leachate extraction procedures (EP).

### SEM and X-Ray Diffraction

Ash samples from Heskett Station Unit 1 were characterized using x-ray, SEM and EMPA techniques. The ash which will be produced from Unit 2 is expected to be similar, mineralogically, to that produced by Unit 1 since the feed coal originates from the same mine and the same coal seam(s). This assumption is confirmed, in part, by diffractograms from Unit 2 ash (generated during a test burn in a 6-foot by 6-foot model of the generator) which show similar mineralogy to the ash generated by Unit 1.

### SEM Analysis

Two samples, one fly ash and the other bottom ash (both from Unit 1), were analyzed using the JEOL 35C scanning electron microscope and microprobe housed in the MMRRI's Natural Materials Analytical Laboratory (NMAL). Operating conditions were set with a beam current of 15 kv and

beam energy of 1,000 picoamps. Samples which were chemically analyzed were mounted in epoxy, polished and carbon coated. Samples used for morphological comparison, size analysis and photography were coated with gold, using the sputtering technique.

The greatest single difference between the fly and bottom ash is their morphology. A large percentage of the fly ash is composed of very small spheres known as cenospheres (Fisher et al., 1976). The cenospheres are typically hollow and calcium-rich. Other irregular forms of particulate matter are also common within the fly ash. The size distribution of the individual grains of Heskett fly ash ranges from less than 5 microns to as large as 175 microns.

The bottom ash is very irregular in morphology when compared to the Heskett fly ash. The size distribution of this ash ranges from less than 10 microns to larger than 2cm. The surfaces of individual grains are porous and jagged. The bottom ash grains tend to be silica-rich and this mineral phase makes them quite rigid.

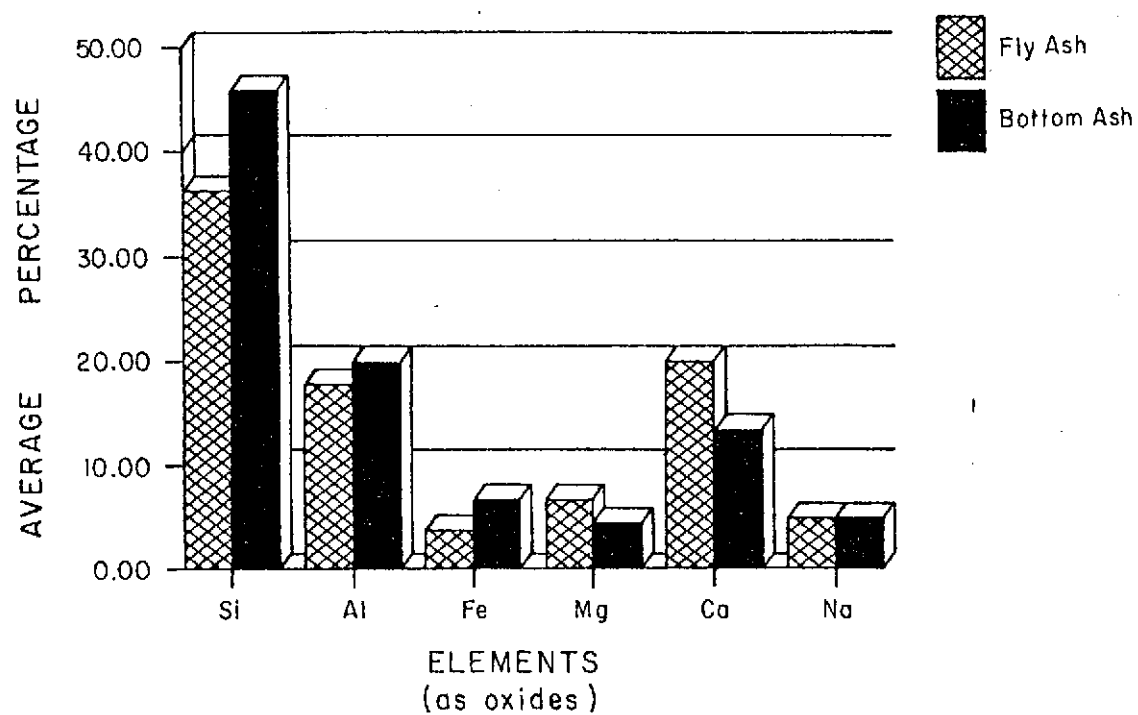
Fifty grains in each sample of ash were analyzed using the SEM microprobe. The data were reduced to oxide mineral phases and normalized using the Bence-Albee fitting routine with silicate standards (Goldstein et al., 1981).

From the microprobe analyses it is clear that the major elements present in the ash are silicon, aluminum, calcium, iron, magnesium and sodium. Figure 24 illustrates that the Heskett bottom ash tends to contain greater concentrations of Si, Al and Fe phases while the fly ash was richer in Ca and Mg phases. The bulk mineralogy of the above elements were determined using x-ray diffraction techniques and will be discussed later in this section.

Figure 24. Summary of SEM microprobe analyses of the chemical composition (illustrated as oxides) of Heskett Station Unit 1 fly and bottom ash.

## FLY ASH VS BOTTOM ASH

Microprobe Analysis



A classification system for coal-ash has been devised by Dr. Robert Stevenson (Director MMRRRI's NMAL). The system is based on natural breaks in point distributions of ash when it is plotted on a Si-Ca-Al ternary diagram. Three types of ash are recognized: 1) the G-type or glass-type, 2) the Q-type or quartz type and 3) the C-type or calcium-type (Stevenson, 1986). It was found, using the above classification system, that both the fly and bottom ash generated within Heskett Station Unit 1 are G-types (glass-types). On a ternary diagram this type of ash would contain less than 84% Si, less than 45% Ca and greater than 10% Al. Such a composition suggests that the ash consists of aluminosilicate crystalline phases.

#### X-Ray Diffraction Analysis

Two samples of fly ash (one sample from each of the two Units) and one sample of bottom ash (from Heskett Unit 1) were analyzed using x-ray diffraction techniques. The samples were analyzed using the NMAL's Philips high-angle diffractometer with a copper access tube. The samples were analyzed from  $15^{\circ}$  through  $60^{\circ}$  at a rate of  $1/2^{\circ}$   $2\theta$  per minute. The strip chart was set at 280 with a time constant of 2 and chart speed of 30. Search manuals were used to identify the mineral peaks on the strip charts.

Several mineral phases were identified using the x-ray diffractometer. Table 4 is a summary of the phases positively identified. The presence of abundant glass phases complicated mineral identification by causing severe peak overlap.

The intensity of the quartz  $[\text{SiO}_2]$  and melilite  $[\text{Ca}_2(\text{Mg,Al})(\text{Al,Si})_{12}\text{O}_{24}(\text{SO}_4)_{1-2}]$  peaks were much stronger in the bottom ash when compared

to those of the fly ash. The fly ash, on the other hand, had high intensity peaks of alkali sulfates  $[(Na,K)_2SO_4]$ , anhydrite  $[CaSO_4]$  and periclase  $[MgO]$ . From the bulk mineralogy (Table 4) it is clear that the most soluble mineral phases present are lime, anhydrite, calcite and the alkali sulfates. The more soluble phases appear to be concentrated in the fly ash.

#### Leachate Analysis

Leachate was extracted separately from the four different ash types which are to be co-disposed of in the proposed MDU Heskett ash disposal site. The EPA-EP leaching procedure Method 1310 (EP toxicity test), without adjustment of pH (the acetic acid step was omitted), was administered on all four ash types. The tests were performed by Minnesota Valley Testing Inc., of New Ulm, Minnesota. The results of the tests were reported to MDU on November 11, 1986 (Verwey, personal communication, 1986). Table 5 gives the results of the EP toxicity tests performed on fly ash from Units 1 and 2. Table 6 gives the results of extraction tests run on bottom ash from Units 1 and 2.

Both the fly and bottom ash samples used for the EP toxicity tests were collected from the Unit 1 hoppers by MDU personnel. The samples were canned and shipped to the lab for testing. The ash samples for Unit 2 were obtained from Babcock and Wilcox (B&W), the design contractor of the fluidized bed system which is currently being



TABLE 4

Minerals Phases Identified in Heskett  
Station Unit 1 Fly and Bottom Ash

<u>Name</u>	<u>Composition</u>
Quartz	$\text{SiO}_2$
Anhydrite	$\text{CaSO}_4$
Merwinite	$\text{Ca}_3\text{Mg}(\text{SiO}_4)_2$
Calcite	$\text{CaCO}_3$
Periclase	$\text{MgO}$
Lime	$\text{CaO}$
Ferrite Spinel	$(\text{Mg,Fe})(\text{Fe,Al})_2\text{O}_4$
Dicalcium Silicate	$\text{Ca}_2\text{SiO}_4$
Melilite	$\text{Ca}_2(\text{Mg,Al})(\text{Al,Si})_{12}\text{O}_{24}(\text{SO}_4)_{1-2}$
Alkali Sulfates	$(\text{Na,K})_2\text{SO}_4$

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TABLE 5

Heskett Station  
Fly Ash Leachate Extraction Results

Parameter	Unit 1 Fly Ash	Unit 2 Fly Ash
Specific Conductance (umhos/cm)	15001	10870
pH (standard units)	12.6	11.9
Total Dissolved Solids (mg/L)	10389	8324
Total Alkalinity as $\text{CaCO}_3$ (mg/L)	1472	598
Hardness as $\text{CaCO}_3$ (mg/L)	238	263
Bicarbonate as $\text{CaCO}_3$ (mg/L)	150	80.5
Boron (mg/L)	1.18	1.70
Carbonate as $\text{CaCO}_3$ (mg/L)	1323	517.5
Calcium (mg/L)	95.0	105.0
Chloride (mg/L)	23.0	21.0
Fluoride (mg/L)	0.22	0.27
Iron (mg/L)	0.2	0.1
Magnesium (mg/L)	0.1	0.1
Potassium (mg/L)	100	100
Nitrate (mg/L)	<1.0	<1.0
Sodium (mg/L)	2200	2350
Sulfate (mg/L)	6550	6160
TRACE ELEMENTS:		
Arsenic (mg/L)	0.070	0.045
Barium (mg/L)	<0.5	<0.5
Cadmium (mg/L)	0.02	0.03
Chromium (mg/L)	<.05	<.05
Lead (mg/L)	0.40	0.25
Manganese (mg/L)	0.01	<.01
Mercury (mg/L)	<.002	<.002
Molybdenum (mg/L)	<.50	<.50
Selenium (mg/L)	0.003	0.004
Silver (mg/L)	<.05	<.05

TABLE 6

Heskett Station  
Bottom Ash Leachate Extraction Results

	Unit 1 Bottom Ash	Unit 2 Bottom Ash
Specific Conductance (umhos/cm)	2544	7066
pH (standard units)	11.5	10.7
Total Dissolved Solids (mg/L)	1357	5774
Total Alkalinity as $\text{CaCO}_3$ (mg/L)	414	173
Hardness as $\text{CaCO}_3$ (mg/L)	194	1429
Bicarbonate as $\text{CaCO}_3$ (mg/L)	161	69.0
Boron (mg/L)	0.91	1.20
Carbonate as $\text{CaCO}_3$ (mg/L)	253	103.5
Calcium (mg/L)	77.5	570.0
Chloride (mg/L)	19.0	5.0
Fluoride (mg/L)	0.11	<.10
Iron (mg/L)	0.2	0.2
Magnesium (mg/L)	0.1	1.4
Potassium (mg/L)	15.0	40.0
Nitrate (mg/L)	<1.0	<1.0
Sodium (mg/L)	380	1200
Sulfate (mg/L)	900	4300
TRACE ELEMENTS:		
Arsenic (mg/L)	<.002	0.155
Barium (mg/L)	<0.5	<0.5
Cadmium (mg/L)	<.01	0.02
Chromium (mg/L)	<.05	<.05
Lead (mg/L)	<.10	0.35
Manganese (mg/L)	<.01	<.01
Mercury (mg/L)	<.002	<.002
Molybdenum (mg/L)	<.50	<.50
Selenium (mg/L)	<.003	<.003
Silver (mg/L)	<.05	<.05

installed within Unit 2. The Unit 2 ash was generated during a "test burn" in a small scale model of the fluidized bed steam generation system. The same coal that feeds Unit 1 was used for the Unit 2 "test burn".

The results of the EP testing directly reflect the mineralogical composition of the ash types. This is especially noticeable in terms of the sulfate concentrations, which are nearly an order of magnitude higher in the fly ash as opposed to the bottom ash (Tables 5 and 6). X-ray diffraction analyses indicated that the fly ash contained abundant alkali sulfate mineral phases, which is one possible source of the elevated sulfate concentrations. A comparison of the  $\text{Na}^+$  and  $\text{K}^+$  ionic concentrations confirms that the  $\text{SO}_4^{2-}$  is, at least in part, contributed to the leachate by the dissolution of the alkali sulfate mineral phases. Both potassium and sodium are concentrated in the fly ash leachate at levels two to five times greater than in the bottom ash. These two ions, along with sulfate, are the major elements of the alkali sulfate mineral phases (Table 4).

The pH of the ash leachates are extremely high, indicating a very alkali solution. As would be expected the fly ashes from Units 1 and 2 are more alkali than their respective bottom ashes. The pH of the leachate is one of the factors that controls the release of trace elements which are locked in the lattice structures of various mineral phases (Groenewold et al., 1980). If the pH of the leachate solutions were acidic the trace elements would be more profound and problematic in their appearance (Wangen and Jones, 1984).

Carbonate ( $\text{CaCO}_3$ ) levels are much higher in the fly ash when compared to those of the bottom ash. Total alkalinity reflects this trend. The system is loaded with carbonate mineral phases, which are relatively soluble and are responsible for the high pH levels observed in the fly and bottom ash samples.

Calcium concentrations are below 105 mg/L in all samples except for Unit 2 bottom ash. The concentration obtained for extracted leachate from Unit 2 was 570 mg/L; well above the other values. Several factors may be responsible for this higher than expected level. These include experimental error, equipment error, and poor sampling technique (bias). It must be remembered that the ash generated for "Unit 2" testing/characterization originated from a scaled-down model of the actual fluidized bed system.

Sulfate and sodium concentrations were likewise higher in the fly ashes when compared to those of the bottom ashes. It appears that the alkali sulfate mineral phases present in the lignite before burning are concentrated in the fly ash after burning and are responsible for the high concentration of  $\text{SO}_4^{2-}$  and  $\text{Na}^+$  observed in the leachate. If the alkali sulfates are present one would also expect elevated concentrations of potassium. Indeed, potassium levels are much higher in the fly ash extracts.

Fluoride, iron, magnesium, chloride and nitrate occur in both the fly and bottom ash leachate at very low concentrations. All five parameters are well below primary drinking water standard limits.

Leachate from all ash samples, except Unit 2 bottom ash, exceeded primary drinking water standards for arsenic, cadmium and lead

(standards in Table 3). The coal burning process concentrates the above trace elements in oxide forms which are relatively soluble. Fortunately these ions are readily attenuated by many soil matrices, and especially by silt and clay, both of which are common at the proposed Heskett disposal site. All other trace elements analyzed were near or below detection limits and within primary drinking water standards.

In general, the leachate of the fly and bottom ash samples are comparable, in terms of quality, to the background chemical composition of the groundwater at the Heskett site. Several of the major ions actually occur at lower concentrations in the leachate than in the groundwater. The leachate generated from Unit 1 bottom ash was of much better quality than any groundwater sampled during the course of this project. The fly ash samples produced a more mineralized (higher TDS) leachate than did the bottom ash. Figure 25 gives a summary of the leachate analyses of the ash which will be disposed of in the Heskett disposal site. The trace elements arsenic, cadmium and lead are the only constituents which pose potential water quality problems. However, the concentrations of these elements are low in the leachates (Tables 5 and 6).

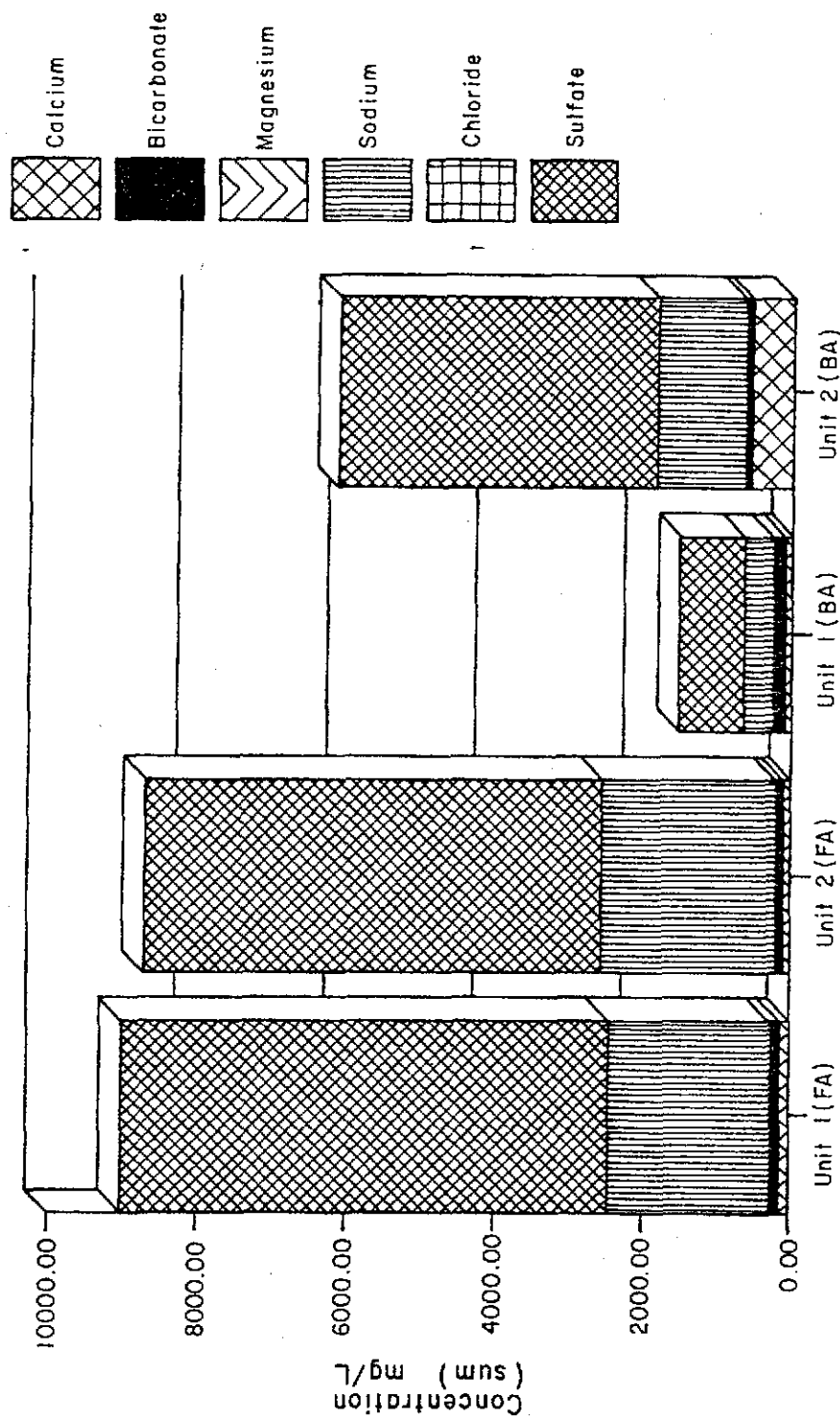
Hassett and Groenewold (1986) have shown that the clay, silt and sand sediments of central and western North Dakota have a strong capacity to buffer highly alkaline leachates and attenuate trace elements such as arsenic and selenium. Groundwater sampling around the existing ash pile at Heskett Station supports their conclusions. The ash pile has been subjected to continuous leaching for the past 30

years. When the quality of the shallow groundwater in the vicinity of the ash pile is compared to background groundwater quality upgradient, there is no detectable difference. In fact, the groundwater quality upgradient is often poorer than the water quality very near to the ash pile.

Figure 25. Summary of the EPA-EP toxicity test results for the Heskett Station ashes. The abbreviations FA and BA refer to fly ash and bottom ash, respectively.



# EPA-EP TOXICITY TEST Fly and Bottom Ash



## DISCUSSION

The purpose of this investigation was to locate a suitable disposal site for lignite combustion ash generated at Montana-Dakota Utilities' R.M. Heskett Station. This 100 megawatt coal-fired power plant is located approximately 3 miles north of Mandan, North Dakota. The approach used in the selection of this disposal site was unconventional in the sense that site selection was based primarily upon hydrogeologic and hydrogeochemical parameters which are often overlooked or given cursory consideration in the site selection process. The trend of previous siting investigations has been to locate a disposal site, based exclusively on proximal considerations, and then engineer the site to meet prescribed regulatory criteria. These sites are often located in settings where the near-surface materials have relatively high permeabilities. Consequently, the major task is often to engineer the site so that it will have sufficiently low permeability characteristics such that leachate migration, and thus possible groundwater contamination, are prevented. The end result of this approach is that a costly man-made or man-introduced liner must be installed at these sites.

The premise of this investigation was that; given a sufficiently large area of study, a disposal site could be located in which the naturally occurring materials would have permeability characteristics

similar to those of a lined disposal site. Ideally, the naturally-occurring material of the site would have a very low permeability, preferably less than  $10^{-7}$  cm/sec, which would prevent leachate migration and have a high clay and silt content which would promote attenuation of potentially toxic trace elements leached from the ash. Additionally, such a disposal site should be isolated from potable groundwater supplies.

The key to successful development and implementation of the landfill disposal method is the prevention of leachate formation. The most apparent way to do this is by isolating the waste from surface water and groundwater sources. In other words, place the ash above the saturated zone and minimize meteoric infiltration from above. Once the waste mass is isolated from water sources, leachate generation is minimized. Beaver (1986) identified coal-waste isolation as the single most important factor in preventing leachate generation and migration in western North Dakota disposal site settings.

Subsurface drilling at the proposed Heskett disposal site revealed the presence of texturally desirable materials. Specifically, the site was characterized by silt- and clay-rich materials which could control leachate migration and promote toxic trace element attenuation with minimal engineering redesign. Installation of observation wells at this site showed a sufficiently deep water table for disposal pit construction.

## Leachate Generation and Migration

The largest single concern in developing a landfill for ash disposal is the potential generation and migration of highly mineralized leachate. If mineralized leachate moves outside of the contained disposal site degradation of groundwater supplies can occur.

Surface capping and revegetation are two operational processes which will greatly aid in minimization of meteoric infiltration. Capping disposal cells with the clay-rich materials available at the proposed Heskett disposal site can maximize runoff and minimize infiltration. Revegetation will also help to maximize evapotranspiration and prevent erosion of the sloped disposal cells.

Some leachate will be produced during the operational phase of disposal. This is inevitable because some precipitation will fall upon the working face of the disposal pit. However, this leachate source can be minimized by maintaining a small working face and by continual reclamation of disposal cells up to the working face.

The leachate that is produced during the operational phase of ash disposal will be contained within the pit by the low permeability silty-clay sediments present at the site. These low permeability sediments will serve two purposes. First, they will prevent the leachate from moving outside of the pit confines and secondly, they will aid in the attenuation of problematic trace elements such as arsenic, cadmium, selenium and lead.

## Groundwater Chemistry and Attenuation Processes

The chemical quality of the existing groundwater at the proposed Heskett ash disposal site is quite variable, but generally very poor. TDS indicate that the water is brackish to saline with an average TDS concentration of 8,000 mg/L. The leachate produced during the EPA-EP toxicity tests (Method 1310) had an average TDS concentration of 6,500 mg/L, with the fly ash extracts producing a more mineralized solution. The above comparison shows that the leachate produced by the ash is of comparable quality to the background groundwater at the Heskett site.

The main parameters of concern, as indicated by the EP toxicity tests performed on the Heskett ash, are arsenic, cadmium and lead. Sorptive, precipitation and co-precipitation processes are the major attenuation mechanisms that effect the concentrations of these dissolved elements. Hassett and Groenewold (1986) studied trace element attenuation capabilities of coal-bearing Tertiary overburden deposits of central and western North Dakota. They found that the pH of a given leachate and the alkaline buffering capacity of the geologic media were the most critical variables in trace element attenuation. Western fly ash leachates are very alkaline with pH values as high as 13. In order to buffer such a solution, one of two possible events must occur, either protons ( $H^+$ ) must be added or hydroxyls ( $OH^-$ ) must be removed. Oxides tend to loose protons in strongly alkaline solutions. This  $H^+$  source, along with other acid producing reactions such as pyrite oxidation and organic decomposition, are the main alkaline buffering reactions. The

protons that are liberated during these reactions will tend to neutralize the hydroxyl ions, thereby lowering the pH of the solution. The pH of the leachate will be buffered until it reaches equilibrium with the groundwater. In central and western North Dakota equilibrium is generally attained at a pH value of between 7 and 9 (Groenewold et al., 1983; Koob and Groenewold, 1984).

Direct precipitation of cadmium and lead occur at pH values above 6.5. The solubility product of lead carbonate ( $\text{PbCO}_3$ ) at 18 °C is  $3.3 \times 10^{-14}$ . In groundwater systems which contain abundant carbonate, lead will be precipitated as lead carbonate, thereby maintaining dissolved lead at low concentrations (Beaver, 1986 and 1987). The same type of reaction maintains cadmium at very low concentrations. Groenewold and Hassett (1986) found that cadmium was removed in excess of 99 percent during laboratory experiments with reduced and oxidized silts. Beaver (1986) confirmed the attenuation capabilities of similar geologic media during a coal-ash field monitoring program near Center, North Dakota. He noted that several ions including arsenic, cadmium and lead were very mobile under alkaline conditions within the ash itself. However, the alkaline leachate was buffered as soon as it came into contact with the surrounding clay and silt deposits. As the pH became lower the concentrations of cadmium and lead were greatly reduced (Beaver, 1986). Arsenic attenuation is also controlled by solution pH. Laboratory experiments performed by Hassett and Groenewold (1986) have shown that arsenic, as  $\text{As}^{5+}$ , is significantly attenuated by the Tertiary sediments of western North Dakota. Arsenic appears to be most strongly attenuated

in the pH range of 7-9. The mobility of selenium is similar to that of arsenic and the same attenuation processes control its concentration in groundwater systems.

Sorptive processes are apparently responsible for arsenic attenuation, though these processes are not well understood at this time. The ability of geologic media to attenuate arsenic has been documented (Hassett and Groenewold, 1986); however, the mechanisms of attenuation have not yet been specifically defined. It appears that cation and anion adsorption on clay particles and hydroxide coatings are important mechanisms in attenuating arsenic and other trace elements.

#### Disposal Site Operational Aspects

The operation of the proposed Heskett ash disposal site will ultimately dictate the volume of leachate produced. The main goal of the operational plan is to minimize water and ash contact. This goal can be achieved in two ways. First, the coal-ash can be emplaced 5-10 feet above the highest recorded position of the water table. The buffer zone between the pit bottom and the water table will consist of in situ clay and silt. Second, a low permeability cap composed of clay and silt removed during pit construction can be placed over the ash, thereby isolating it from contact with infiltrating meteoric water. The cap can be sloped to maximize runoff and revegetated to maximize evapotranspiration.

Use of *in situ* natural materials for leachate containment, as is being proposed for use at the Heskett site, allows for more effective disposal planning. For example, we propose the opening of small disposal "cells" at the Heskett site. The cell disposal method will be advantageous from two standpoints. First, it will permit easy and effective drainage management. Secondly, it will prevent MDU from having to open the entire proposed disposal area at the beginning of operation to install a liner. This would degrade the landscape, cause surface drainage problems and lead to the production of a greater volume of leachate than would be produced by taking advantage of the intrinsic characteristics of the proposed site.

#### Potential Disposal Site Impacts

Groundwater flow will not be significantly affected by the emplacement of ash in this particular setting. The disposal site can be constructed in such a manner as to leave a sufficiently thick buffer zone between the pit bottom and the water table. This buffer zone will allow for seasonal fluctuations in the position of the water table and promote attenuation of potentially toxic trace elements. Covering the disposal cells with low permeability materials excavated during pit construction will minimize meteoric infiltration. Prevention of ash and water contact is the key to successful operation of this disposal site because doing so will minimize the formation of highly mineralized leachate, and eliminate the opportunity for groundwater mounding to occur beneath the site. Groundwater mounding and leachate production are ubiquitous problems in humid regions which receive more



precipitation than the semiarid region in which the proposed coal-ash disposal site is located.

With proper disposal site design, the chemistry of the groundwater at the proposed Heskett disposal site will not be affected by the emplacement of ash in this setting. Water and ash interaction will be minimized by operational techniques and, consequently, there will be very little leachate produced. As noted above, the composition of the background groundwater in the pre-disposal setting, and the ash leachate simulated during the EPA-EP toxicity testing, are of comparable quality. Therefore, if some leachate is produced and enters the groundwater flow regime, it will not appreciably change the composition of the groundwater. For example, well 60 contained groundwater with a sulfate concentration of 11,632 mg/L. The greatest concentration of sulfate leached from the ash was 6,550 mg/L; considerably lower than the sulfate concentrations in typical groundwater in the predisposal setting. The same overall trend is reflected in TDS, with the simulated leachate having similar or lower concentrations than the groundwater in the pre-disposal setting. Problematic trace elements such as arsenic, cadmium and lead will be effectively attenuated by sorption and precipitation mechanisms. Attenuation of these trace elements is pH dependent. As the pH of an initially alkaline (pH 10-13) solution is buffered (pH 6-9), these particular trace elements are removed from that solution through the mechanisms listed above.

The discussion thus far has been based on the "ideal" setting. The remaining question to be answered is, what will happen if the design criteria are not followed, or fail due to an unpredictable rise in the

position of the water table? If meteoric water is allowed to infiltrate from the ground surface then continuous leaching and groundwater mounding may occur. Continuous leaching could cause degradation of the shallow groundwater in the vicinity of the ash disposal pit. Potential contamination of groundwater in a continuous leaching setting would be much more severe than in a controlled leaching setting due to the large volumes of leachate produced. Mounding would further expedite groundwater/leachate interaction and lead to a downward component of leachate flow from the disposal site (Freeze and Cherry, 1979, p. 436). The actual change in groundwater chemistry due to continuous interaction with the ash is, at this time, unknown because long-term leaching tests have not been performed on Heskett Station ash. Hassett and others (1985) have shown that secondary reactions between gasification ash residue and leaching solution are important in precipitation (fixation) of specific elements such as alumina and boron. However, the extent of the reactions and their applicability to Heskett Station lignite-ash are presently unknown.

From the above discussion, it becomes apparent that the most desirable disposal setting is one that is dry. Dry disposal settings are generally in oxidizing environments, provided there is a lack of organic material, where pe and pH values are relatively high. Optimum adsorption of leachate is attained in these settings (Drever, 1982). Furthermore, the leachate generation potential will be maintained at low levels if surface water and groundwater are prevented from interacting with the ash.

## SUMMARY AND CONCLUSIONS

Design and implementation of a "site assessment program" was an important and necessary first step in this investigation. During this stage desirable site characteristics were described and addressed. For example, desirable site characteristics for ash disposal listed at the beginning of this investigation were: relatively flat topography, water table 25-30 feet (or more) below the ground surface, isolation from potable groundwater sources, isolation from residential areas and presence of low permeability materials such as silt and clay in the upper 30 (or more) feet of the site. If low permeability materials ( $K \approx 10^{-6}$  cm/sec) are present, the need for a liner can, in some cases, be eliminated. Of course, the required containment permeability is a waste dependent variable. For coal-ash disposal,  $10^{-7}$  cm/sec is an acceptable pit permeability (Tillotson, personal communication, 1986).

Transportation and hauling costs were considered before potential disposal sites were selected. After these costs were estimated, an effective radius was drawn around the waste generation site (Heskett Station). This radius represented the maximum distance of economically feasible transport and hauling of ash. Once the desirable site characteristics were described and transportation costs estimated, selection of potentially suitable sites began.

During the early portion of this investigation, several sites were selected, based on the desirable characteristics described above. The final two candidate disposal sites selected had similar geologic and geohydrologic settings. Therefore, the site closest to Heskett Station

was selected for detailed evaluation. This proposed coal-ash disposal site (referred to as the "Heskett site") is located one-quarter mile west of Heskett Station.

Characterization of the Heskett site began during the summer of 1986. Since that time 27 monitoring wells have been installed at the proposed site. The conclusions of the investigation and recommendations for ash disposal operations at this site can be summarized as follows:

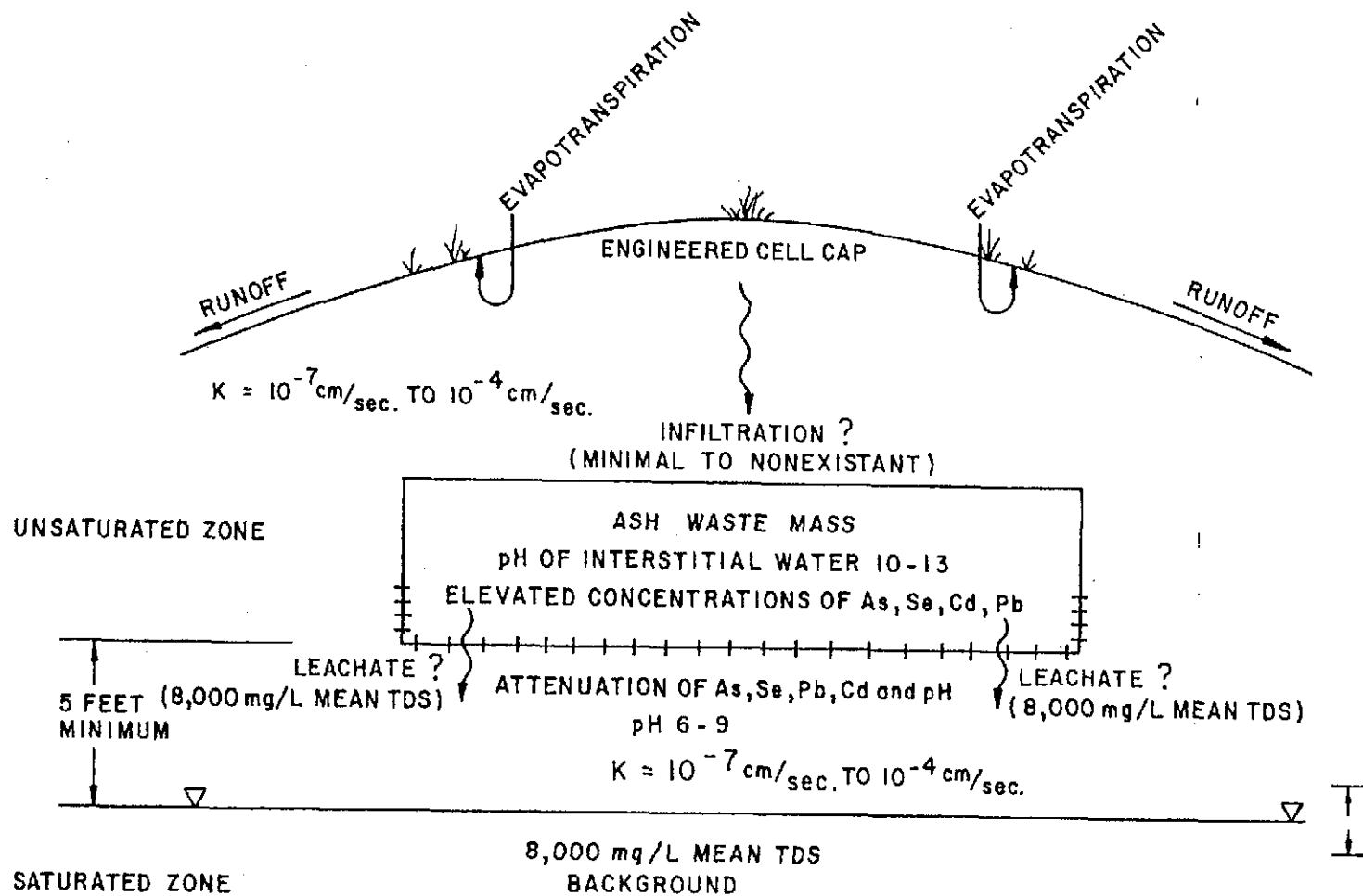
1. Silt- and clay-rich lithologies sampled at the proposed Heskett disposal site have low permeabilities, on the order of  $10^{-7}$  cm/sec. However, secondary fracturing may be locally present and could be responsible for local areas of relatively high permeabilities ( $K = 4.5 \times 10^{-4}$  cm/sec).
2. The shallow groundwater in the pre-disposal setting at the proposed Heskett site is highly mineralized, with TDS concentrations commonly exceeding 8,000 mg/L.
3. EPA-EP toxicity test ash-leachate is comparable to the background groundwater quality at the proposed Heskett site, with TDS averaging 8,000 mg/L. Problematic trace elements leached from the ash, such as arsenic, cadmium and lead have been shown to be effectively attenuated by Tertiary silts and clays of central and western North Dakota (Hassett and Groenewold, 1986 and Hassett, 1987).
4. During the operational phase of ash disposal the objective should be to minimize leachate production. This can be accomplished by

maintaining a dry disposal setting through the opening and continual reclamation of small disposal "cells". Cell surface caps should be constructed of the low permeability materials excavated during pit construction. The cell surfaces should also be sloped to maximize runoff and minimize infiltration. A dry disposal setting can be further assured by maintaining a 5- to 10-foot buffer/attenuation zone between the pit bottom and the highest recorded elevation of the water table.

Figure 26 is a conceptual sketch of a Heskett site disposal cell. The sketch applies the conclusions and recommendations described above and from previous work by several different authors. The figure shows a relatively complex solution for ash disposal in this particular environment. The concepts from this figure can be applied elsewhere within the Northern Great Plains with only minor modifications.

If the disposal site design criteria described in this thesis are followed, coal-ash emplaced in this setting will have a minimal impact on groundwater quality, and in general, on the geohydrologic flow regime at the proposed disposal site.

Figure 26. Diagrammatic cross-sectional sketch of a typical Heskett site ash disposal cell after reclamation.



## APPENDICES



## APPENDIX A

Heskett Site Well Completion Reports

Well Number: 10

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10CCD

Elevation: Ground; 1722.06 ft. Casing top; 1725.01 ft.  
Well Bottom; 1604.01 ft.

Completion: Date drilled; 8-12-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry;  
some air-mist

Boring: Diameter; 5 5/8 in. Depth drilled; 120 ft.  
Encountered water (below surface); 65 ft.  
Geophysical log recorded

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.90-115.30 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 115.30-119.30 ft.  
Elevation of interval; 1604.01-1608.01 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 114-120 ft.

Grout Seal: Depths (from ground); 0-114 ft.  
Date sealed; 8-13-86

Additional Data:

Static Water Level: Date; 8-21-86  
Depth; 51.97 ft. below top of casing  
Elevation; 1673.04 ft.

Chemistry: Date; 8-21-86  
pH; 7.75 Sp. cond; 11050 micromhos/cm  
Temp; 8.9 oC

Well Number: 11

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10CCD

Elevation: Ground; 1722.10 ft. Casing top; 1725.01 ft.  
Well Bottom; 1642.81 ft.

Completion: Date drilled; 8-12-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry;  
some air-mist

Boring: Diameter; 5 5/8 in. Depth drilled; 80 ft.  
Encountered water (below surface); 65 ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.90-78.20 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 78.20-82.20 ft.  
Elevation of interval; 1642.81-1646.81 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 77-79 ft.

Grout Seal: Depths (from ground); 0-77 ft.  
Date sealed; 8-13-86

Additional Data:

Static Water Level: Date; 8-21-86  
Depth; 43.83 ft. below top of casing  
Elevation; 1681.18 ft.

Chemistry: Date; 8-21-86  
pH; 7.75 Sp. cond; 9840 micromhos/cm  
Temp; 8.6 oC

Well Number: 12

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10CCD

Elevation: Ground; 1721.88 ft. Casing top; 1724.90 ft.  
Well Bottom; 1643.51 ft.

Completion: Date drilled; 8-12-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry;  
some air-mist

Boring: Diameter; 5 5/8 in. Depth drilled; 80 ft.  
Encountered water (below surface); 65 ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +3.02-58.37 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 58.37-78.37 ft.  
Elevation of interval; 1643.51-1663.51 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 57-79 ft.

Grout Seal: Depths (from ground); 0-57 ft.  
Date sealed; 8-13-86

Additional Data:

Static Water Level: Date; 8-21-86  
Depth; 43.60 ft. below top of casing  
Elevation; 1681.30 ft.

Chemistry: Date; 8-21-86  
pH; 7.60 Sp. cond; 11440 micromhos/cm  
Temp; 8.5 oC

Well Number: 13

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10CCD

Elevation: Ground; 1721.88 ft. Casing top; 1724.90 ft.  
Well Bottom; 1681.88 ft.

Completion: Date drilled; 11-13-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry

Boring: Diameter; 5 5/8 in. Depth drilled; 40 ft.  
Encountered water (below surface); ? ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +3.02-20.37 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC Depths (from  
ground); 20.37-40.37 ft.  
Elevation of interval; 1681.51-1701.51 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 19-41 ft.

Grout Seal: Depths (from ground); 0-19 ft.  
Date sealed; 1-27-87

Additional Data:

Static Water Level: Date; 12-15-86  
Depth; 30.09 ft. below top of casing  
Elevation; 1694.81 ft.

Chemistry: Date; NA  
pH; NA Sp. cond; NA  
Temp; NA

Well Number: 20

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10CAC

Elevation: Ground; 1707.04 ft. Casing top; 1709.48 ft.  
Well Bottom; 1627.48 ft.

Completion: Date drilled; 8-12-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry

Boring: Diameter; 5 5/8 in. Depth drilled; 80 ft.  
Encountered water (below surface); 45 ft.  
Geophysical log recorded

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.44-75.56 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 75.56-79.56 ft.  
Elevation of interval; 1627.48-1631.48 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 74-80 ft.

Grout Seal: Depths (from ground); 0-74 ft.  
Date sealed; 8-13-86

Additional Data:

Static Water Level: Date; 8-21-86  
Depth; 37.96 ft. below top of casing  
Elevation; 1671.52 ft.

Chemistry: Date; 8-21-86  
pH; 7.98 Sp. cond; 4970 micromhos/cm  
Temp; 8.7 oC

Well Number: 21

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10CAC

Elevation: Ground; 1707.22 ft. Casing top; 1709.40 ft.  
Well Bottom; 1661.90 ft.

Completion: Date drilled; 8-12-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry;

Boring: Diameter; 5 5/8 in. Depth drilled; 50 ft.  
Encountered water (below surface); 45 ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.66-21.32 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 21.32-45.32 ft.  
Elevation of interval; 1661.90-1685.90 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 20-46 ft.

Grout Seal: Depths (from ground); 0-20 ft.  
Date sealed; 8-13-86

Additional Data:

Static Water Level: Date; 8-21-86  
Depth; 29.33 ft. below top of casing  
Elevation; 1680.07 ft.

Chemistry: Date; 8-21-86  
pH; 6.95 Sp. cond; 13920 micromhos/cm  
Temp; 8.5 oC

Well Number: 30

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10CBA

Elevation: Ground; 1715.55 ft. Casing top; 1717.64 ft.  
Well Bottom; 1595.64 ft.

Completion: Date drilled; 8-12-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry;  
some air-mist

Boring: Diameter; 5 5/8 in. Depth drilled; 120 ft.  
Encountered water (below surface); 60 ft.  
Geophysical log recorded

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.90-115.91 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 115.91-119.91 ft.  
Elevation of interval; 1595.64-1599.64 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 114-120 ft.

Grout Seal: Depths (from ground); 0-114 ft.  
Date sealed; 8-13-86

Additional Data:

Static Water Level: Date; 8-21-86  
Depth; 49.41 ft. below top of casing  
Elevation; 1668.23 ft.

Chemistry: Date; 8-21-86  
pH; 7.95 Sp. cond; 1993 micromhos/cm  
Temp; 8.6 oC



Well Number: 31

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10CBA

Elevation: Ground; 1715.24 ft. Casing top; 1717.58 ft.  
Well Bottom; 1635.58 ft.

Completion: Date drilled; 8-12-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry;  
some air-mist

Boring: Diameter; 5 5/8 in. Depth drilled; 80 ft.  
Encountered water (below surface); 60 ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.34-75.66 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 75.66-79.66 ft.  
Elevation of interval; 1635.58-1639.58 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 74-80 ft.

Grout Seal: Depths (from ground); 0-74 ft.  
Date sealed; 8-13-86

Additional Data:

Static Water Level: Date; 8-21-86  
Depth; 43.54 ft. below top of casing  
Elevation; 1674.04 ft.

Chemistry: Date; 8-21-86  
pH; 7.96 Sp. cond; 1993 micromhos/cm  
Temp; 7.8 oC

Well Number: 32

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10CBA

Elevation: Ground; 1715.34 ft. Casing top; 1717.79 ft.  
Well Bottom; 1641.69 ft.

Completion: Date drilled; 8-12-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry;  
some air-mist

Boring: Diameter; 5 5/8 in. Depth drilled; 80 ft.  
Encountered water (below surface); 60 ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.45-53.65 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 53.65-73.65 ft.  
Elevation of interval; 1641.69-1661.69 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 52-75 ft.

Grout Seal: Depths (from ground); 0-52 ft.  
Date sealed; 8-13-86

Additional Data:

Static Water Level: Date; 8-21-86  
Depth; 42.03 ft. below top of casing  
Elevation; 1675.76 ft.

Chemistry: Date; 8-21-86  
pH; 7.22 Sp. cond; 3000 micromhos/cm  
Temp; 8.0 oC

Well Number: 33

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10CBA

Elevation: Ground; 1715.34 ft. Casing top; 1717.79 ft.  
Well Bottom; 1672.79 ft.

Completion: Date drilled; 11-13-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry

Boring: Diameter; 5 5/8 in. Depth drilled; 45 ft.  
Encountered water (below surface); ? ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.45-25.65 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 25.65-45.65 ft.  
Elevation of interval; 1669.69-1689.69 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 24-45 ft.

Grout Seal: Depths (from ground); 0-24 ft.  
Date sealed; 1-27-87

Additional Data:

Static Water Level: Date; 12-15-86  
Depth; 40.68 ft. below top of casing  
Elevation; 1677.11 ft.

Chemistry: Date; NA  
pH; NA Sp. cond; NA  
Temp; NA

Well Number: 40

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10CDB

Elevation: Ground; 1708.02 ft. Casing top; 1710.15 ft.  
Well Bottom; 1592.25 ft.

Completion: Date drilled; 8-13-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry;  
some air-mist

Boring: Diameter; 5 5/8 in. Depth drilled; 120 ft.  
Encountered water (below surface); 50 ft.  
Geophysical log recorded

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.13-111.77 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 111.77-115.77 ft.  
Elevation of interval; 1592.25-1596.25 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 110-117 ft.

Grout Seal: Depths (from ground); 0-117 ft.  
Date sealed; 8-13-86

Additional Data:

Static Water Level: Date; 8-21-86  
Depth; 63.72 ft. below top of casing  
Elevation; 1646.43 ft.

Chemistry: Date; 8-21-86  
pH; 7.58 Sp. cond; 6260 micromhos/cm  
Temp; 8.2 °C

Well Number: 41

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10CDB

Elevation: Ground; 1708.03 ft. Casing top; 1710.07 ft.  
Well Bottom; 1626.77 ft.

Completion: Date drilled; 8-13-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry;  
some air-mist

Boring: Diameter; 5 5/8 in. Depth drilled; 82 ft.  
Encountered water (below surface); 50 ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.04-77.26 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 77.26-81.26 ft.  
Elevation of interval; 1626.77-1630.77 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 76-82 ft.

Grout Seal: Depths (from ground); 0-76 ft.  
Date sealed; 8-13-86

Additional Data:

Static Water Level: Date; 8-21-86  
Depth; 36.58 ft. below top of casing  
Elevation; 1673.49 ft.

Chemistry: Date; 8-21-86  
pH; 7.57 Sp. cond; 5480 micromhos/cm  
Temp; 8.4 oC

Well Number: 42

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10CDB

Elevation: Ground; 1708.12 ft. Casing top; 1710.31 ft.  
Well Bottom; 1652.61 ft.

Completion: Date drilled; 8-13-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry;  
some air-mist

Boring: Diameter; 5 5/8 in. Depth drilled; 60 ft.  
Encountered water (below surface); 50 ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.19-35.51 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 35.51-55.51 ft.  
Elevation of interval; 1652.61-1672.61 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 34-56 ft.

Grout Seal: Depths (from ground); 0-34 ft.  
Date sealed; 8-13-86

Additional Data:

Static Water Level: Date; 8-21-86  
Depth; 32.88 ft. below top of casing  
Elevation; 1677.43 ft.

Chemistry: Date; 8-21-86  
pH; 7.22 Sp. cond; 5060 micromhos/cm  
Temp; 8.6 oC

Well Number: 43

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10CDD

Elevation: Ground; 1708.92 ft. Casing top; 1711.03 ft.  
Well Bottom; 1650.14 ft.

Completion: Date drilled; 9-18-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry

Boring: Diameter; 5 5/8 in. Depth drilled; 60 ft.  
Encountered water (below surface); 25 ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.11-54.78 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 54.78-58.78 ft.  
Elevation of interval; 1650.14-1654.14 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 53-59 ft.

Grout Seal: Depths (from ground); 0-53 ft.  
Date sealed; 9-18-86

Additional Data:

Static Water Level: Date; 10-4-86  
Depth; 25.85 ft. below top of casing  
Elevation; 1685.18 ft.

Chemistry: Date; 10-4-86  
pH; 6.70 Sp. cond; 6950 micromhos/cm  
Temp; 8.5 oC

Well Number: 44

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10CDD

Elevation: Ground; 1709.09 ft. Casing top; 1711.40 ft.  
Well Bottom; 1685.88 ft.

Completion: Date drilled; 9-18-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry

Boring: Diameter; 5 5/8 in. Depth drilled; 25 ft.  
Encountered water (below surface); 25 ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.31-3.21 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 3.21-23.54 ft.  
Elevation of interval; 1685.88-1705.88 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 2.5-24.0 ft.

Grout Seal: Depths (from ground); 0-2.5 ft.  
Date sealed; 9-18-86

Additional Data:

Static Water Level: Date; 10-4-86  
Depth; 21.92 ft. below top of casing  
Elevation; 1689.48 ft.

Chemistry: Date; 10-4-86  
pH; 6.72 Sp. cond; 10270 micromhos/cm  
Temp; 9.1 oC



Well Number: 45

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10CDB

Elevation: Ground; 1708.12 ft. Casing top; 1710.31 ft.  
Well Bottom; 1668.12 ft.

Completion: Date drilled; 11-13-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry;

Boring: Diameter; 5 5/8 in. Depth drilled; 40 ft.  
Encountered water (below surface); ? ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.19-20.51 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 20.51-40.51 ft.  
Elevation of interval; 1667.61-1687.61 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 19-41 ft.

Grout Seal: Depths (from ground); 0-19 ft.  
Date sealed; 1-27-86

Additional Data:

Static Water Level: Date; 12-15-86  
Depth; 28.71 ft. below top of casing  
Elevation; 1681.60 ft.

Chemistry: Date; NA  
pH; NA Sp. cond; NA  
Temp; NA

Well Number: 50

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10CAD

Elevation: Ground; 1674.58 ft. Casing top; 1677.01 ft.  
Well Bottom; 1647.51 ft.

Completion: Date drilled; 8-13-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry;  
some air-mist

Boring: Diameter; 5 5/8 in. Depth drilled; 30 ft.  
Encountered water (below surface); 17 ft.  
Geophysical log recorded

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.43-7.07 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 7.07-27.07 ft.  
Elevation of interval; 1647.51-1667.51 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 6-29 ft.

Grout Seal: Depths (from ground); 0-6 ft.  
Date sealed; 8-13-86

Additional Data:

Static Water Level: Date; 8-21-86  
Depth; 5.45 ft. below top of casing  
Elevation; 1671.56 ft.

Chemistry: Date; 8-21-86  
pH; 7.56 Sp. cond; 6480 micromhos/cm  
Temp; 10.8 oC

Well Number: 51

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10CAD

Elevation: Ground; 1674.47 ft. Casing top; 1676.70 ft.  
Well Bottom; 1637.33 ft.

Completion: Date drilled; 9-18-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry;  
some air-mist

Boring: Diameter; 5 5/8 in. Depth drilled; 40 ft.  
Encountered water (below surface); 18 ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.23-32.14 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 32.14-37.14 ft.  
Elevation of interval; 1637.33-1642.33 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 31-38 ft.

Grout Seal: Depths (from ground); 0-31 ft.  
Date sealed; 9-18-86

Additional Data:

Static Water Level: Date; 10-4-86  
Depth; 5.77 ft. below top of casing  
Elevation; 1670.93 ft.

Chemistry: Date; 10-4-86  
pH; 7.46 Sp. cond; 3700 micromhos/cm  
Temp; 8.2 oC

Well Number: 52

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10CAD

Elevation: Ground; 1674.45 ft. Casing top; 1676.71 ft.  
Well Bottom; 1658.01 ft.

Completion: Date drilled; 9-18-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry;  
some air-mist

Boring: Diameter; 5 5/8 in. Depth drilled; 20 ft.  
Encountered water (below surface); 18 ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.26-6.44 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 6.44-16.44 ft.  
Elevation of interval; 1658.01-1668.01 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 5-18 ft.

Grout Seal: Depths (from ground); 0-5 ft.  
Date sealed; 9-18-86

Additional Data:

Static Water Level: Date; 10-4-86  
Depth; 4.13 ft. below top of casing  
Elevation; 1672.58 ft.

Chemistry: Date; 10-4-86  
pH; 7.29 Sp. cond; 6300 micromhos/cm  
Temp; 9.4 oC

Well Number: 53

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10DCC

Elevation: Ground; 1685.71 ft. Casing top; 1688.17 ft.  
Well Bottom; 1665.70 ft.

Completion: Date drilled; 9-18-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry

Boring: Diameter; 5 5/8 in. Depth drilled; 21 ft.  
Encountered water (below surface); 15 ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.46-5.01 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 5.01-20.01 ft.  
Elevation of interval; 1665.70-1680.70 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 4-21 ft.

Grout Seal: Depths (from ground); 0-4 ft.  
Date sealed; 9-18-86

Additional Data:

Static Water Level: Date; 10-4-86  
Depth; 6.30 ft. below top of casing  
Elevation; 1681.87 ft.

Chemistry: Date; 10-4-86  
pH; NA Sp. cond; NA micromhos/cm  
Temp; NA °C

Well Number: 54

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10DCC

Elevation: Ground; 1685.71 ft. Casing top; 1688.10 ft.  
Well Bottom; 1633.11 ft.

Completion: Date drilled; 9-18-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry

Boring: Diameter; 5 5/8 in. Depth drilled; 60 ft.  
Encountered water (below surface); 15 ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.39-47.60 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 47.60-52.60 ft.  
Elevation of interval; 1633.11-1638.11 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 46-54 ft.

Grout Seal: Depths (from ground); 0-46 ft.  
Date sealed; 9-18-86

Additional Data:

Static Water Level: Date; 10-4-86  
Depth; 15.16 ft. below top of casing  
Elevation; 1672.94 ft.

Chemistry: Date; 10-4-86  
pH; 9.55 Sp. cond; 1100 micromhos/cm  
Temp; 9.8 oC

Well Number: 55

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10DCA

Elevation: Ground; 1693.86 ft. Casing top; 1696.10 ft.  
Well Bottom; 1636.95 ft.

Completion: Date drilled; 9-18-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry

Boring: Diameter; 5 5/8 in. Depth drilled; 60 ft.  
Encountered water (below surface); 45 ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.24-31.91 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 31.91-56.91 ft.  
Elevation of interval; 1636.95-1661.95 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 30-58 ft.

Grout Seal: Depths (from ground); 0-30 ft.  
Date sealed; 9-18-86

Additional Data:

Static Water Level: Date; 10-4-86  
Depth; 29.46 ft. below top of casing  
Elevation; 1666.64 ft.

Chemistry: Date; 10-4-86  
pH; 6.81 Sp. cond; 10840 micromhos/cm  
Temp; 8.5 °C

Well Number: 56

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-80-10DCA

Elevation: Ground; 1693.86 ft. Casing top; 1696.42 ft.  
Well Bottom; 1597.99 ft.

Completion: Date drilled; 9-18-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry

Boring: Diameter; 5 5/8 in. Depth drilled; 100 ft.  
Encountered water (below surface); 45 ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.56-91.87 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 91.87-96.87 ft.  
Elevation of interval; 1597.99-1601.99 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 90-98 ft.

Grout Seal: Depths (from ground); 0-90 ft.  
Date sealed; 9-18-86

Additional Data:

Static Water Level: Date; 10-4-86  
Depth; 42.03 ft. below top of casing  
Elevation; 1654.39 ft.

Chemistry: Date; 10-4-86  
pH; 8.44 Sp. cond; 4160 micromhos/cm  
Temp; 8.3 oC



Well Number: 60

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-18-10CDB

Elevation: Ground; 1714.23 ft. Casing top; 1716.42 ft.  
Well Bottom; 1662.02 ft.

Completion: Date drilled; 8-13-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry;  
some air-mist

Boring: Diameter; 5 5/8 in. Depth drilled; 60 ft.  
Encountered water (below surface); 45 ft.  
Geophysical log recorded

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.19-22.21 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 22.21-52.21 ft.  
Elevation of interval; 1662.02-1692.02 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 21-54 ft.

Grout Seal: Depths (from ground); 0-21 ft.  
Date sealed; 8-13-86

Additional Data:

Static Water Level: Date; 8-21-86  
Depth; 31.01 ft. below top of casing  
Elevation; 1685.41 ft.

Chemistry: Date; 8-21-86  
pH; 6.94 Sp. cond; 15760 micromhos/cm  
Temp; 8.5 °C

Well Number: 61

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10CDA

Elevation: Ground; 1714.23 ft. Casing top; 1716.53 ft.  
Well Bottom; 1670.89 ft.

Completion: Date drilled; 9-18-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry

Boring: Diameter; 5 5/8 in. Depth drilled; 46 ft.  
Encountered water (below surface); 37 ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.30-13.34 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 13.34-43.34 ft.  
Elevation of interval; 1670.89-1700.89 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 12-45 ft.

Grout Seal: Depths (from ground); 0-12 ft.  
Date sealed; 9-18-86

Additional Data:

Static Water Level: Date; 10-4-86  
Depth; 32.58 ft. below top of casing  
Elevation; 1683.95 ft.

Chemistry: Date; 10-4-86  
pH; 6.83 Sp. cond; 12750 micromhos/cm  
Temp; 8.4 oC

Well Number: 62

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10CDB

Elevation: Ground; 1714.32 ft. Casing top; 1716.67 ft.  
Well Bottom; 1681.40 ft.

Completion: Date drilled; 9-18-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry

Boring: Diameter; 5 5/8 in. Depth drilled; 35 ft.  
Encountered water (below surface); 35 ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.35-12.92 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 12.92-32.91 ft.  
Elevation of interval; 1681.40-1701.40 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 11-34 ft.

Grout Seal: Depths (from ground); 0-11 ft.  
Date sealed; 9-18-86

Additional Data:

Static Water Level: Date; 10-4-86  
Depth; 32.74 ft. below top of casing  
Elevation; 1683.93 ft.

Chemistry: Date; 10-4-86  
pH; 6.71 Sp. cond; 13170 micromhos/cm  
Temp; 9.3 oC

Well Number: 70

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-16ABA

Elevation: Ground; 1733.18 ft. Casing top; 1735.67 ft.  
Well Bottom; 1634.57 ft.

Completion: Date drilled; 8-13-86  
Driller; Mohl Drilling, Beulah, ND  
Method of drilling; Air rotary, dry;  
some air-mist

Boring: Diameter; 5 5/8 in. Depth drilled; 102 ft.  
Encountered water (below surface); 45 ft.  
Geophysical log recorded

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.49-94.61 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 94.61-98.61 ft.  
Elevation of interval; 1634.57-1638.57 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 93-99 ft.

Grout Seal: Depths (from ground); 0-93 ft.  
Date sealed; 8-13-86

Additional Data:

Static Water Level: Date; 8-21-86  
Depth; 54.20 ft. below top of casing  
Elevation; 1681.47 ft.

Chemistry: Date; 8-21-86  
pH; 7.85 Sp. cond; 13000 micromhos/cm  
Temp; 10.1 oC

Well Number: 80 (WS2)

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10DCC

Elevation: Ground; 1696.00 ft. Casing top; 1698.64 ft.  
Well Bottom; 1607.00 ft.

Completion: Date drilled; 9-23-81  
Driller; Water Supply, Inc.  
Method of drilling; NA

Boring: Diameter; NA in. Depth drilled; 90 ft.  
Encountered water (below surface); NA ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +3-56, 61-89 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 56-61 ft.  
Elevation of interval; 1635.00-1640.00 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 53-62 ft.

Grout Seal: Depths (from ground); 0-52 ft.  
Date sealed; NA

Additional Data:

Static Water Level: Date; 10-4-86  
Depth; 33.86 ft. below top of casing  
Elevation; 1664.78 ft.

Chemistry: Date; 8-21-86  
pH; 7.04 Sp. cond; 3760 micromhos/cm  
Temp; 8.6 oC

Well Number: 81 (WS1)

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-DBB

Elevation: Ground; 1679.61 ft. Casing top; 1681.71 ft.  
Well Bottom; 1606.73 ft.  
Repaired casing top (1-13-86); 1683.67 ft.

Completion: Date drilled; 9-22-81  
Driller; Water Supply, Inc.  
Method of drilling; NA

Boring: Diameter; NA in. Depth drilled; 73 ft.  
Encountered water (below surface); NA ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +2.7-40, 45-73 ft.  
(as of 1-13-87); +4.7-40, 45-73 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 40-45 ft.  
Elevation of interval; 1634.61-1639.61 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 37-47 ft.

Grout Seal: Depths (from ground); 0-37 ft.  
Date sealed; NA

Additional Data:

Static Water Level: Date; 8-21-86  
Depth; 24.61 ft. below top of casing  
Elevation; 1657.10 ft.

Chemistry: Date; 8-21-86  
pH; 7.47 Sp. cond; 1899 micromhos/cm  
Temp 7.0 oC

Well Number: 82 (WS1A)

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-DBB

Elevation: Ground; 1679.10 ft. Casing top; 1682.23 ft.  
Well Bottom; 1657.10 ft.

Completion: Date drilled; 8-5-85  
Driller; Water Supply, Inc.  
Method of drilling; NA

Boring: Diameter; NA in. Depth drilled; 23 ft.  
Encountered water (below surface); NA ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +3.2-17 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 17-22 ft.  
Elevation of interval; 1657.10-1662.10 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 15-23 ft.

Grout Seal: Depths (from ground); 0-15 ft.  
Date sealed; NA

Additional Data:

Static Water Level: Date; 8-21-86  
Depth; DRY ft. below top of casing  
Elevation; ft.

Chemistry: Date: 8-21-86  
pH; NA Sp. cond; NA micromhos/cm  
Temp; NA °C

Well Number: 83 (WSIB)

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10DBB

Elevation: Ground; 1678.80 ft. Casing top; 1682.07 ft.  
Well Bottom; 1648.80 ft.

Completion: Date drilled; 8-6-85  
Driller; Water Supply, Inc.  
Method of drilling; NA

Boring: Diameter; NA in. Depth drilled; 30 ft.  
Encountered water (below surface); NA ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +3.3-25 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 25-30 ft.  
Elevation of interval; 1648.80-1653.80 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 23-30 ft.

Grout Seal: Depths (from ground); 0-22 ft.  
Date sealed; NA

Additional Data:

Static Water Level: Date; 8-21-86  
Depth; 24.48 ft. below top of casing  
Elevation; 1657.59 ft.

Chemistry: Date; 8-21-86  
pH; 7.07 Sp. cond; 3940 micromhos/cm  
Temp; 8.5 oC



Well Number: 84 (WS4)

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10DBA

Elevation: Ground; 1659.61 ft. Casing top; 1662.61 ft.  
Well Bottom; 1607.60 ft.

Completion: Date drilled; 9-24-81  
Driller; Water Supply, Inc.  
Method of drilling; NA

Boring: Diameter; NA in. Depth drilled; 52 ft.  
Encountered water (below surface); NA ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +3-30, 35-52 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 30-35 ft.  
Elevation of interval; 1624.60-1629.60 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 27-36 ft.

Grout Seal: Depths (from ground); 0-26 ft.  
Date sealed; NA

Additional Data:

Static Water Level: Date; 9-4-86  
Depth; 19.62 ft. below top of casing  
Elevation; 1642.99 ft.

Chemistry: Date; NA  
pH; NA Sp. cond; NA micromhos/cm  
Temp; NA °C

Well Number: 85 (WS4A)

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10DBA

Elevation: Ground; 1659.49 ft. Casing top; 1662.49 ft.  
Well Bottom; 1641.50 ft.

Completion: Date drilled; 9-24-81  
Driller; Water Supply, Inc.  
Method of drilling; NA

Boring: Diameter; NA in. Depth drilled; 18 ft.  
Encountered water (below surface); NA ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +3-13 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 13-18 ft.  
Elevation of interval; 1641.50-1646.50 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 11-18 ft.

Grout Seal: Depths (from ground); 0-11 ft.  
Date sealed; NA

Additional Data:

Static Water Level: Date; 9-4-86  
Depth; 17.29 ft. below top of casing  
Elevation; 1645.20 ft.

Chemistry: Date; NA  
pH; NA Sp. cond; NA micromhos/cm  
Temp; NA oC

Well Number: 86 (WS4B)

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10DBA

Elevation: Ground; 1659.75 ft. Casing top; 1662.75 ft.  
Well Bottom; 1635.80 ft.

Completion: Date drilled; 8-5-85  
Driller; Water Supply, Inc.  
Method of drilling; NA

Boring: Diameter; NA in. Depth drilled; 25 ft.  
Encountered water (below surface); NA ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +3.1-19.0 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 19-24 ft.  
Elevation of interval; 1635.80-1640.80 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 18-25 ft.

Grout Seal: Depths (from ground); 0-18 ft.  
Date sealed; NA

Additional Data:

Static Water Level: Date; 9-4-86  
Depth; 17.39 ft. below top of casing  
Elevation; 1645.36 ft.

Chemistry: Date; NA  
pH; NA Sp. cond; NA micromhos/cm  
Temp; NA °C

Well Number: 87 (WS3)

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10DBA

Elevation: Ground; 1658.00 ft. Casing top; 1661.00 ft.  
Well Bottom; 1608.00 ft.

Completion: Date drilled; 9-21-81  
Driller; Water Supply, Inc.  
Method of drilling; NA

Boring: Diameter; NA in. Depth drilled; 50 ft.  
Encountered water (below surface); NA ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +3-25, 30-50 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 25-30 ft.  
Elevation of interval; 1628.00-1633.00 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 24-32 ft.

Grout Seal: Depths (from ground); 0-23 ft.  
Date sealed; NA

Additional Data:

Static Water Level: Date; 9-4-86  
Depth; 14.67 ft. below top of casing  
Elevation; 1646.33 ft.

Chemistry: Date; NA  
pH; NA Sp. cond; NA micromhos/cm  
Temp; NA oC

Well Number: 88 (WS3A)

Project: MDU Ash Disposal Program

Construction Data:

Location: 139-81-10DBA

Elevation: Ground; 1657.70 ft. Casing top; 1660.81 ft.  
Well Bottom; 1645.31 ft.

Completion: Date drilled; 8-5-85  
Driller; Water Supply, Inc.  
Method of drilling; NA

Boring: Diameter; NA in. Depth drilled; 13 ft.  
Encountered water (below surface); NA ft.

Casing: Diameter; 2 in. Material; Sch. 40 PVC  
Depths (from ground); +3.1-7.5 ft.

Screen: Diameter; 2 in. Slot size; 20  
Material; Factory slotted PVC  
Depths (from ground); 7.5-12.5 ft.  
Elevation of interval; 1645.31-1650.31 ft.

Sand Pack: Type of sand; Washed sand  
Depths (from ground); 6-13 ft.

Grout Seal: Depths (from ground); 0-6 ft.  
Date sealed; NA

Additional Data:

Static Water Level: Date; 10-4-86  
Depth; 8.37 ft. below top of casing  
Elevation; 1652.44 ft.

Chemistry: Date; NA  
pH; NA Sp. cond; NA micromhos/cm  
Temp; NA oC

## APPENDIX B

Heskett Site Water Level Data

## Well 10

Elevation at Top of PVC Casing: 1725.01 ft.

Elevation of Ground Surface: 1722.06 ft.

Elevation of Screened Interval: 1604.01-1608.01 ft.

Date Installed: 8-12-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
8-15-86	13.86	45.47	1679.54	
8-21-86	15.84	51.97	1673.04	-6.50
9-4-86	15.68	51.45	1673.56	0.52
9-11-86	15.74	51.64	1673.37	-0.20
10-4-86	16.04	52.63	1672.38	-0.98
10-16-86	16.25	53.32	1671.69	-0.69
11-10-86	16.21	53.19	1671.82	0.13
11-21-86	16.33	53.58	1671.43	-0.39
1-13-87	16.37	53.71	1671.30	-0.13
1-28-87	16.37	53.71	1671.30	0.00
3-6-87	16.34	53.61	1671.40	0.10
4-21-87	16.29	53.45	1671.56	0.16

## Well 11

Elevation at Top of PVC Casing: 1725.01 ft.

Elevation of Ground Surface: 1722.10 ft.

Elevation of Screened Interval: 1642.81-1646.81 ft.

Date Installed: 8-12-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
8-15-86	13.32	43.70	1681.31	
8-21-86	13.36	43.83	1681.18	-0.13
9-4-86	13.22	43.37	1681.64	0.46
9-11-86	12.93	42.42	1682.59	0.95

10-4-86	12.69	41.64	1683.37	0.79
10-16-86	12.64	41.47	1683.54	0.16
11-10-86	12.40	40.68	1684.33	0.79
11-21-86	12.46	40.88	1684.13	-0.20
1-13-87	12.41	40.72	1684.29	0.16
1-28-87	12.40	40.68	1684.33	0.03
3-6-87	12.37	40.59	1684.42	0.10
4-21-87	12.41	40.72	1684.29	-0.13

Well 12 -

Elevation at Top of PVC Casing: 1724.90 ft.

Elevation of Ground Surface 1721.88 ft.

Elevation of Screened Interval: 1643.51-1663.51 ft.

Date Installed: 8-12-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
8-15-86	13.23	43.41	1681.49	
8-21-86	13.29	43.60	1681.30	-0.20
9-4-86	13.12	43.05	1681.85	0.56
9-11-86	12.93	42.42	1682.48	0.62
10-4-86	12.48	40.95	1683.95	1.48
10-16-86	12.36	40.55	1684.35	0.39
11-10-86	12.29	40.32	1684.58	0.23
11-21-86	12.19	40.00	1684.90	0.33
1-13-87	12.15	39.86	1685.04	0.13
1-28-87	12.12	39.77	1685.13	0.10
3-6-87	12.12	39.77	1685.13	0.00
4-21-87	12.14	39.83	1685.07	-0.07



## Well 13

Elevation at Top of PVC Casing: 1724.90 ft.

Elevation of Ground Surface 1721.88 ft.

Elevation of Screened Interval: 1643.51-1663.51 ft.

Date Installed: 11-13-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
12-15-86	9.17	30.09	1694.81	
1-13-87	9.14	29.99	1694.91	0.10
1-28-87	9.14	29.99	1694.91	0.00
3-6-87	9.19	30.15	1694.75	-0.16
4-21-87	9.12	29.92	1694.98	0.23

## Well 20

Elevation at Top of PVC Casing: 1709.48 ft.

Elevation of Ground Surface: 1707.04 ft.

Elevation of Screened Interval: 1627.48-1631.48 ft.

Date Installed: 8-12-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
8-15-86	11.57	37.96	1671.52	
8-21-86	11.57	37.96	1671.52	0.00
9-4-86	11.53	37.83	1671.65	0.13
9-11-86	11.33	37.17	1672.31	0.66
10-4-86	11.23	36.85	1672.63	0.33
10-16-86	11.23	36.85	1672.63	0.00
11-10-86	11.25	36.91	1672.57	-0.07
11-21-86	11.20	36.75	1672.73	0.16
1-13-87	11.18	36.68	1672.80	0.07
1-28-87	11.15	36.58	1672.90	0.10
3-6-87	11.00	36.09	1673.39	0.49
4-21-87	10.89	35.73	1673.75	0.36

## Well 21

Elevation at Top of PVC Casing: 1709.40 ft.

Elevation of Ground Surface: 1707.22 ft.

Elevation of Screened Interval: 1661.90-1685.90 ft.

Date Installed: 8-12-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
8-15-86	8.92	29.27	1680.13	
8-21-86	8.94	29.33	1680.07	-0.07
9-4-86	8.91	29.23	1680.17	0.10
9-11-86	8.89	29.17	1680.23	0.07
10-4-86	8.84	29.00	1680.40	0.16
10-16-86	8.82	28.94	1680.46	0.07
11-10-86	8.80	28.87	1680.53	0.07
11-21-86	8.72	28.61	1680.79	0.26
1-13-87	8.69	28.51	1680.89	0.10
1-28-87	8.67	28.45	1680.95	0.07
3-6-87	8.66	28.41	1680.99	0.03
4-21-87	8.52	27.95	1681.45	0.46

## Well 30

Elevation at Top of PVC Casing: 1717.64 ft.

Elevation of Ground Surface: 1715.55 ft.

Elevation of Screened Interval: 1595.64-1599.64 ft.

Date Installed: 8-12-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
8-15-86	14.99	49.18	1668.46	
8-21-86	15.06	49.41	1668.23	-0.23
9-4-86	15.06	49.41	1668.23	0.00
9-11-86	15.05	49.38	1668.26	0.03

10-4-86	15.02	49.28	1668.36	0.10
10-16-86	15.04	49.35	1668.29	-0.07
11-10-86	14.96	49.08	1668.56	0.26
11-21-86	15.02	49.28	1668.36	-0.20
1-13-87	14.98	49.15	1668.49	0.13
1-28-87	14.92	48.95	1668.69	0.20
3-6-87	14.79	48.53	1669.11	0.43
4-21-87	14.66	48.10	1669.54	0.43

## Well 31

Elevation at Top of PVC Casing: 1717.58 ft.

Elevation of Ground Surface: 1715.24 ft.

Elevation of Screened Interval: 1635.58-1639.58 ft.

Date Installed: 8-12-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
8-15-86	13.07	42.88	1674.70	
8-21-86	13.27	43.54	1674.04	-0.66
9-4-86	13.13	43.08	1674.50	0.46
9-11-86	13.17	43.21	1674.37	-0.13
10-4-86	13.01	42.69	1674.89	0.52
10-16-86	13.33	43.74	1673.84	-1.05
11-10-86	13.35	43.80	1673.78	-0.07
11-21-86	13.33	43.74	1673.84	0.07
1-13-87	13.23	43.41	1674.17	0.33
1-28-87	13.18	43.24	1674.34	0.16
3-6-87	12.98	42.59	1674.99	0.66
4-21-87	12.88	42.26	1675.32	0.33

## Well 32

Elevation at Top of PVC Casing: 1717.79 ft.

Elevation of Ground Surface: 1715.34 ft.

Elevation of Screened Interval: 1641.69-1661.69 ft.

Date Installed: 8-12-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
8-15-86	12.77	41.90	1675.89	
8-21-86	12.81	42.03	1675.76	-0.13
9-4-86	12.91	42.36	1675.43	-0.33
9-11-86	12.96	42.52	1675.27	-0.16
10-4-86	12.77	41.90	1675.89	0.62
10-16-86	12.81	42.03	1675.76	-0.13
11-10-86	12.82	42.06	1675.73	-0.03
11-21-86	12.76	41.87	1675.92	0.20
1-13-87	12.55	41.18	1676.61	0.69
1-28-87	12.53	41.11	1676.68	0.07
3-6-87	12.28	40.29	1677.50	0.82
4-21-87	12.19	40.00	1677.79	0.30

## Well 33

Elevation at Top of PVC Casing: 1717.79 ft.

Elevation of Ground Surface: 1715.34 ft.

Elevation of Screened Interval: 1641.69-1661.69 ft.

Date Installed: 11-13-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
12-15-86	12.40	40.68	1677.11	
1-13-87	12.41	40.72	1677.07	-0.03
1-28-87	12.36	40.55	1677.24	0.16
3-6-87	12.11	39.73	1678.06	0.82
4-21-87	11.89	39.01	1678.78	0.72

## Well 40

Elevation at Top of PVC Casing: 1710.15 ft.

Elevation of Ground Surface: 1708.02 ft.

Elevation of Screened Interval: 1592.25-1596.25 ft.

Date Installed: 8-12-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
8-15-86	16.40	53.81	1656.34	
8-21-86	19.42	63.72	1646.43	-9.91
9-4-86	19.45	63.82	1646.33	-0.10
9-11-86	19.45	63.82	1646.33	0.00
10-4-86	19.42	63.72	1646.43	0.10
10-16-86	19.41	63.68	1646.47	0.03
11-10-86	19.23	63.09	1647.06	0.59
11-21-86	19.29	63.29	1646.86	-0.20
1-13-87	19.32	63.39	1646.76	-0.10
1-28-87	19.30	63.32	1646.83	0.07
3-6-87	19.22	63.06	1647.09	0.26
4-21-87	19.25	63.16	1646.99	-0.10

## Well 41

Elevation at Top of PVC Casing: 1710.07 ft.

Elevation of Ground Surface: 1708.03 ft.

Elevation of Screened Interval: 1626.77-1630.77 ft.

Date Installed: 8-12-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
8-15-86	11.23	36.85	1673.22	
8-21-86	11.15	36.58	1673.49	0.26
9-4-86	11.08	36.35	1673.72	0.23
9-11-86	11.06	36.29	1673.78	0.07

10-4-86	10.98	36.03	1674.04	0.26
10-16-86	11.00	36.09	1673.98	-0.07
11-10-86	10.92	35.83	1674.24	0.26
11-21-86	10.95	35.93	1674.14	-0.10
1-13-87	11.02	36.16	1673.91	-0.23
1-28-87	11.02	36.16	1673.91	0.00
3-6-87	10.92	35.83	1674.24	0.33
4-21-87	10.80	35.43	1674.64	0.39

## Well 42

Elevation at Top of PVC Casing: 1710.31 ft.

Elevation of Ground Surface: 1708.12 ft.

Elevation of Screened Interval: 1652.61-1672.61 ft.

Date Installed: 8-12-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
8-15-86	9.60	31.50	1678.81	
8-21-86	10.02	32.88	1677.43	-1.38
9-4-86	10.25	33.63	1676.68	-0.75
9-11-86	10.15	33.30	1677.01	0.33
10-4-86	9.74	31.96	1678.35	1.35
10-16-86	9.98	32.74	1677.57	-0.79
11-10-86	9.65	31.66	1678.65	1.08
11-21-86	9.58	31.43	1678.88	0.23
1-13-87	9.59	31.46	1678.85	-0.03
1-28-87	9.56	31.37	1678.94	0.10
3-6-87	9.53	31.27	1679.04	0.10
4-21-87	9.51	31.20	1679.11	0.07

## Well 43

Elevation at Top of PVC Casing: 1711.03 ft.

Elevation of Ground Surface: 1708.92 ft.

Elevation of Screened Interval: 1650.14-1654.14 ft.

Date Installed: 9-18-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
10-4-86	7.88	25.85	1684.46	
10-16-86	7.93	26.02	1684.29	-0.16
11-10-86	7.85	25.76	1684.55	0.26
11-21-86	7.87	25.82	1684.49	-0.07
1-13-87	7.95	26.08	1684.23	-0.26
1-28-87	7.99	26.22	1684.09	-0.13
3-6-87	7.89	25.89	1684.42	0.33
4-21-87	7.96	26.12	1684.19	-0.23

## Well 44

Elevation at Top of Casing: 1711.40 ft.

Elevation of Ground Surface: 1709.09 ft.

Elevation of Screened Interval: 1685.88-1705.88 ft.

Date Installed: 9-18-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
10-4-86	6.68	21.92	1689.48	
10-16-86	6.70	21.98	1689.42	-0.07
11-10-86	6.71	22.02	1689.38	-0.03
11-13-86	6.70	21.98	1689.42	0.03
11-21-86	6.66	21.85	1689.55	0.13
1-13-87	6.75	22.15	1689.25	-0.30
1-28-87	6.78	22.25	1689.15	-0.10
3-6-87	6.72	22.05	1689.35	0.20
4-21-87	6.62	21.72	1689.68	0.33

## Well 45

Elevation at Top of PVC Casing: 1710.31 ft.

Elevation of Ground Surface: 1708.12 ft.

Elevation of Screened Interval: 1652.61-1672.61 ft.

Date Installed: 11-13-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
12-15-86	8.75	28.71	1681.60	
1-13-87	8.71	28.58	1681.73	0.13
1-28-87	8.65	28.38	1681.93	0.20
3-6-87	8.68	28.48	1681.83	-0.10
4-21-87	8.71	28.58	1681.73	-0.10

## Well 50

Elevation at Top of PVC Casing: 1677.01 ft.

Elevation of Ground Surface: 1674.58 ft.

Elevation of Screened Interval: 1647.51-1667.51 ft.

Date Installed: 8-12-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
8-15-86	1.54	5.05	1671.96	
8-21-86	1.66	5.45	1671.56	-0.39
9-4-86	1.70	5.58	1671.43	-0.13
9-11-86	1.66	5.45	1671.56	0.13
10-4-86	1.28	4.20	1672.81	1.25
10-16-86	1.38	4.53	1672.48	-0.33
11-10-86	1.35	4.43	1672.58	0.10
11-21-86	1.27	4.17	1672.84	0.26
1-13-87	1.45	4.76	1672.25	-0.59
1-28-87	1.45	4.76	1672.25	0.00
3-6-87	NA	NA	NA	NA
4-21-87	1.14	3.74	1673.27	0.93



## Well 51

Elevation at Top of PVC Casing: 1676.70 ft.

Elevation of Ground Surface: 1674.47 ft.

Elevation of Screened Interval: 1637.33-1642.33 ft.

Date Installed: 9-18-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
10-4-86	1.76	5.77	1670.93	
10-16-86	1.96	6.43	1670.27	-0.66
11-10-86	1.93	6.33	1670.37	0.10
11-21-86	1.85	6.07	1670.63	0.26
1-13-87	1.92	6.30	1670.40	-0.23
1-28-87	1.94	6.37	1670.33	-0.07
3-6-87	1.81	5.94	1670.76	0.43
4-21-87	1.66	5.45	1671.25	0.49

## Well 52

Elevation at Top of PVC Casing: 1676.71 ft.

Elevation of Ground Surface: 1674.45 ft.

Elevation of Screened Interval: 1658.01-1668.01 ft.

Date Installed: 9-18-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
10-4-86	1.26	4.13	1672.58	
10-16-86	1.35	4.43	1672.28	-0.30
11-10-86	1.32	4.33	1672.38	0.10
11-21-86	1.24	4.07	1672.64	0.26
1-13-87	1.39	4.56	1672.15	-0.49
1-28-87	1.40	4.59	1672.12	-0.03
3-6-87	1.16	3.81	1672.90	0.79
4-21-87	1.10	3.61	1673.10	0.20

## Well 53

Elevation at Top of PVC Casing: 1688.17 ft.

Elevation of Ground Surface: 1685.71 ft.

Elevation of Screened Interval: 1665.70-1680.70 ft.

Date Installed: 9-18-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
10-4-86	1.92	6.30	1681.87	
10-16-86	2.03	6.66	1681.51	-0.36
11-10-86	1.96	6.43	1681.74	0.23
11-21-86	1.97	6.46	1681.71	-0.03
1-13-87	2.11	6.92	1681.25	-0.46
1-28-87	2.33	7.64	1680.53	-0.72
3-6-87	2.30	7.55	1680.62	0.10
4-21-87	1.88	6.17	1682.00	1.38

## Well 54

Elevation at Top of PVC Casing: 1688.10 ft.

Elevation of Ground Surface: 1685.71 ft.

Elevation of Screened Interval: 1633.11-1638.11 ft.

Date Installed: 9-18-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
10-4-86	4.62	15.16	1672.94	
10-16-86	6.51	21.36	1666.74	-6.20
11-10-86	6.48	21.26	1666.84	0.10
11-21-86	6.39	20.97	1667.13	0.30
1-13-87	6.36	20.87	1667.23	0.10
1-28-87	6.35	20.83	1667.27	0.03
3-6-87	6.40	21.00	1667.10	-0.16
4-21-87	6.31	20.70	1667.40	0.30

## Well 55

Elevation at Top of PVC Casing: 1696.10 ft.

Elevation of Ground Surface: 1693.86 ft.

Elevation of Screened Interval: 1636.95-1661.95 ft.

Date Installed: 9-18-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
10-4-86	8.98	29.46	1666.64	
10-16-86	9.08	29.79	1666.31	-0.33
11-10-86	9.06	29.73	1666.37	0.07
11-21-86	8.99	29.50	1666.60	0.23
1-13-87	9.01	29.56	1666.54	-0.07
1-28-87	9.00	29.53	1666.57	0.03
3-6-87	8.93	29.30	1666.80	0.23
4-21-87	8.93	29.30	1666.80	0.00

## Well 56

Elevation at Top of PVC Casing: 1696.42 ft.

Elevation of Ground Surface: 1693.86 ft.

Elevation of Screened Interval: 1597.99-1601.99 ft.

Date Installed: 9-18-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
10-4-86	12.81	42.03	1654.39	
10-16-86	12.96	42.52	1653.90	-0.49
11-10-86	12.17	39.93	1656.49	2.59
11-21-86	12.17	39.93	1656.49	0.00
1-13-87	12.16	39.90	1656.52	0.03
1-28-87	12.18	39.96	1656.46	-0.07
3-6-87	12.14	39.83	1656.59	0.13
4-21-87	12.01	39.40	1657.02	0.43

## Well 60

Elevation at Top of PVC Casing: 1716.42 ft.

Elevation of Ground Surface: 1714.23 ft.

Elevation of Screened Interval: 1662.02-1692.02 ft.

Date Installed: 8-12-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
8-15-86	9.60	31.50	1684.92	
8-21-86	9.45	31.01	1685.41	0.49
9-4-86	9.93	32.58	1683.84	-1.57
9-11-86	9.93	32.58	1683.84	0.00
10-4-86	9.92	32.55	1683.87	0.03
10-16-86	9.91	32.51	1683.91	0.03
11-10-86	9.91	32.51	1683.91	0.00
11-21-86	9.86	32.35	1684.07	0.16
1-13-87	9.86	32.35	1684.07	0.00
1-28-87	9.85	32.32	1684.10	0.03
3-6-87	9.91	32.51	1683.91	-0.20
4-21-87	9.84	32.29	1684.13	0.23

## Well 61

Elevation at Top of PVC Casing: 1716.53 ft.

Elevation of Ground Surface: 1714.23 ft.

Elevation of Screened Interval: 1670.89-1700.89 ft.

Date Installed: 9-18-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
10-4-86	9.93	32.58	1683.95	
10-16-86	9.92	32.55	1683.98	0.03
11-10-86	9.91	32.51	1684.02	0.03
11-21-86	9.87	32.38	1684.15	0.13

1-13-87	9.87	32.38	1684.15	0.00
1-28-87	9.87	32.38	1684.15	0.00
3-6-87	9.92	32.55	1683.98	-0.16
4-21-87	9.85	32.32	1684.21	0.23

## Well 62

Elevation at Top of PVC Casing: 1716.67 ft.

Elevation of Ground Surface: 1714.32 ft.

Elevation of Screened Interval: 1681.40-1701.40 ft.

Date Installed: 9-18-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
10-4-86	9.98	32.74	1683.93	
10-16-86	9.98	32.74	1683.93	0.00
11-10-86	9.96	32.68	1683.99	0.07
11-21-86	9.92	32.55	1684.12	0.13
1-13-87	9.91	32.51	1684.16	0.03
1-28-87	9.91	32.51	1684.16	0.00
3-6-87	9.97	32.71	1683.96	-0.20
4-21-87	9.90	32.48	1684.19	0.23

## Well 70

Elevation at Top of PVC Casing: 1735.67 ft.

Elevation of Ground Surface: 1733.18 ft.

Elevation of Screened Interval: 1634.57-1638.57 ft.

Date Installed: 8-12-86

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
8-15-86	16.24	53.28	1682.39	
8-21-86	16.52	54.20	1681.47	-0.92
9-4-86	16.80	55.12	1680.55	-0.92

9-11-86	16.77	55.02	1680.65	0.10
10-4-86	16.73	54.89	1680.78	0.13
10-16-86	16.76	54.99	1680.68	-0.10
11-10-86	16.54	54.27	1681.40	0.72
11-21-86	16.63	54.56	1681.11	-0.30
1-13-87	16.60	54.46	1681.21	0.10
1-28-87	16.60	54.46	1681.21	0.00
3-6-87	16.58	54.40	1681.27	0.07
4-21-87	16.62	54.53	1681.14	-0.13

Well 80 (WS2)

Elevation at Top of PVC Casing: 1698.64 ft.

Elevation of Ground Surface: 1696.00 ft.

Elevation of Screened Interval: 1635.00-1640.00 ft.

Date Installed: 9-23-81

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
8-21-86	10.32	33.86	1664.78	
9-4-86	10.35	33.96	1664.68	-0.10
10-4-86	10.26	33.66	1664.98	0.30
10-16-86	10.26	33.66	1664.98	0.00
11-10-86	10.22	33.53	1665.11	0.13
11-21-86	10.20	33.47	1665.17	0.07
1-13-87	10.30	33.79	1664.85	-0.33
1-28-87	10.32	33.86	1664.78	-0.07
3-6-87	10.28	33.73	1664.91	0.13
4-21-87	10.03	32.91	1665.73	0.82

## Well 81 (WS1)

Elevation at Top of PVC Casing: 1681.71 ft.

Elevation of Ground Surface: 1679.61 ft.

Elevation of Screened Interval: 1634.61-1639.61 ft.

Date Installed: 9-22-81

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
8-21-86	7.50	24.61	1657.10	
9-4-86	7.62	25.00	1656.71	-0.39
10-4-86	7.62	25.00	1656.71	0.00
10-16-86	7.66	25.13	1656.58	-0.13
11-10-86	7.80	25.59	1656.12	-0.46
11-21-86	7.79	25.56	1656.15	0.03
1-13-87	8.58*	28.15	1655.52	-0.63
1-28-87	8.42	27.63	1656.04	0.52
3-6-87	8.16	26.77	1656.90	0.85
4-21-87	7.61	24.97	1658.70	1.80

\*new well casing reference level: 1683.67 ft.

## Well 82 (WS1A)

Elevation at Top of PVC Casing: 1682.23 ft.

Elevation of Ground Surface: 1679.10 ft.

Elevation of Screened Interval: 1657.10-1662.10 ft.

Date Installed: 8-5-85

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
8-21-86	dry	0.00		
9-4-86	dry	0.00		0.00
10-4-86	dry	0.00		0.00
10-16-86	dry	0.00		0.00
11-10-86	dry	0.00		0.00

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11-21-86	dry	0.00		0.00
1-13-87	dry	0.00		0.00
1-28-87	dry	0.00		0.00
3-6-87	7.41	24.31	1657.92	NA
4-21-87	6.76	22.18	1660.05	2.13

## Well 83 (WS1B)

Elevation at Top of PVC Casing: 1682.07 ft.

Elevation of Ground Surface: 1678.80 ft.

Elevation of Screened Interval: 1648.80-1653.80 ft.

Date Installed: 8-6-85

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
8-21-86	7.46	24.48	1657.59	
9-4-86	7.68	25.20	1656.87	-0.72
10-4-86	7.72	25.33	1656.74	-0.13
10-16-86	7.78	25.53	1656.54	-0.20
11-10-86	8.00	26.25	1655.82	-0.72
11-21-86	7.95	26.08	1655.99	0.16
1-13-87	8.25	27.07	1655.00	-0.98
1-28-87	7.81	25.62	1656.45	1.44
3-6-87	7.42	24.35	1657.72	1.28
4-21-87	6.65	21.82	1660.25	2.53

## Well 84 (WS4)

Elevation at Top of PVC Casing: 1662.61 ft.

Elevation of Ground Surface: 1659.61 ft.

Elevation of Screened Interval: 1624.60-1629.60 ft.

Date Installed: 9-24-81

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
9-4-86	5.98	19.62	1642.99	
10-4-86	5.95	19.52	1643.09	0.10
10-16-86	5.95	19.52	1643.09	0.00
11-10-86	5.96	19.55	1643.06	-0.03
11-21-86	5.92	19.42	1643.19	0.13
1-13-87	5.74	18.83	1643.78	0.59
1-28-87	5.76	18.90	1643.71	-0.07
3-6-87	5.84	19.16	1643.45	-0.26
4-21-87	5.79	19.00	1643.61	0.16

## Well 85 (WS4A)

Elevation at Top of PVC Casing: 1662.49 ft.

Elevation of Ground Surface: 1659.49 ft.

Elevation of Screened Interval: 1641.50-1646.50 ft.

Date Installed: 9-24-81

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
9-4-86	5.27	17.29	1645.20	
10-4-86	5.23	17.16	1645.45	0.13
10-16-86	5.23	17.16	1645.45	0.00
11-10-86	5.26	17.26	1645.35	-0.10
11-21-86	5.22	17.13	1645.48	0.13
1-13-87	5.30	17.39	1645.22	-0.26
1-28-87	5.30	17.39	1645.22	0.00
3-6-87	5.37	17.62	1644.99	-0.23
4-21-87	4.82	15.81	1646.80	1.80

## Well 86 (WS4B)

Elevation at Top of PVC Casing: 1662.75 ft.

Elevation of Ground Surface: 1659.75 ft.

Elevation of Screened Interval: 1635.80-1640.80 ft.

Date Installed: 8-5-85

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
9-4-86	5.30	17.39	1645.36	
10-4-86	5.24	17.19	1645.56	0.20
10-16-86	5.25	17.23	1645.52	-0.03
11-10-86	5.29	17.36	1645.39	-0.13
11-21-86	5.23	17.16	1645.59	0.20
1-13-87	5.31	17.42	1645.33	-0.26
1-28-87	5.30	17.39	1645.36	0.03
3-6-87	5.38	17.65	1645.10	-0.26
4-21-87	4.82	15.81	1646.94	1.84

Well 87 (WS3)

Elevation at Top of PVC Casing: 1661.00 ft.

Elevation of Ground Surface: 1658.00 ft.

Elevation of Screened Interval: 1628.00-1633.00 ft.

Date Installed: 9-21-81

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
9-4-86	4.47	14.67	1646.33	
10-4-86	4.42	14.50	1646.50	0.16
10-16-86	4.40	14.44	1646.56	0.07
11-10-86	4.44	14.57	1646.43	-0.13
11-21-86	4.39	14.40	1646.60	0.16
1-13-87	4.26	13.98	1647.02	0.43
1-28-87	4.41	14.47	1646.53	-0.49
3-6-87	4.51	14.80	1646.20	-0.33
4-21-87	4.25	13.94	1647.06	0.85

Well 88 (WS3A)

Elevation at Top of PVC Casing: 1660.81 ft.

Elevation of Ground Surface: 1657.70 ft.

Elevation of Screened Interval: 1645.31-1650.31 ft.

Date Installed: 8-5-85

Reference Point: All depths measured from top of PVC casing

Date	Depth to water level (m)	Depth to water level (ft)	Water level elevation (ft)	Change from previous level (ft)
10-4-86	2.55	8.37	1652.44	
10-16-86	2.53	8.30	1652.51	0.07
11-10-86	2.61	8.56	1652.25	-0.26
11-21-86	2.57	8.43	1652.38	0.13
1-13-87	2.91	9.55	1651.26	-1.12
1-28-87	2.99	9.81	1651.00	-0.26
3-6-87	3.10	10.17	1650.64	-0.36
4-21-87	2.08	6.82	1653.99	3.35

## APPENDIX C

## Heskett Site Lithologic Logs

(intervals in the left column are given in feet)

## Wells 10, 11, 12 and 13

- 0-1 Top soil, silty, clayey, sandy, brown, calcareous; with some limestone pebbles.
- 1-11 Silt, clayey, brownish-tan, slightly indurated, very dry, calcareous; with thin coarse-grained, clean silt lenses and a few small (less than .5 in.) iron oxide concretions. Abundant small gypsum crystals (less than .13 in. long). Some small, black flakes of organic plant material. Cannonball-Ludlow Formations.
- 11-14 Silt, as above, with some (less than 20%) very fine- to fine-grained sand interspersed.
- 14-30 Silt, as above, clayey, less sand than above interval, oxidized; with very fine-grained silty sand lenses and very few gypsum crystals.
- 30-41 Silt, very clayey, with some (less than 20%) very fine-grained sand interspersed, steel-gray (color change), moderately indurated; with fewer small gypsum crystals than above intervals.
- 41-59 Silt, as above, very clayey, with some (less than 20%) fine- to medium-grained sand interspersed in a silt and clay matrix.
- 59-65 Silt, as above, with abundant (more than 20%) fine- to medium-grained sand interspersed.
- 65-81 Silt, clayey, steel-gray to bluish, moderately indurated; with thin coarse-grained silt to very fine-grained sand lenses in an otherwise fine silt to clay matrix.
- 81-84 Clay, silty, steel-gray to bluish, moderately indurated, dense.
- 84-91 Siltstone, sandy, clayey, steel-gray to bluish, slightly indurated; with small fine-grained sand lenses and abundant (more than 20%) sand interspersed in the matrix.
- 91-110 Silt, clayey, bluish-gray, moderately indurated; with thin (less than 1 foot) mudstone lenses.
- 110-120 Silt, very clayey, steel-gray to bluish, moderately indurated, very dense. Cannonball-Ludlow Formations.

Wells 20 and 21

- 0-1 Top soil, silty, sandy, clayey, dark-brown, calcareous; with some limestone and granite pebbles.
- 1-21 Silt, clayey, with minor amounts (less than 10%) of very fine-grained sand interspersed, brownish-tan, slightly indurated, calcareous, oxidized; with small iron oxide concretions and abundant small gypsum crystals.  
Cannonball-Ludlow Formations.
- 21-26 Silt, as above, steel-gray (color change).
- 26-49 Silt, clayey, with some (less than 20%) very fine- to medium-grained sand interspersed, steel-gray to bluish, slightly indurated; with very few small gypsum crystals and some thin (less than 1 foot) siltstone lenses.
- 49-53 Silt, as above, with abundant (more than 20%) fine- to medium-grained sand interspersed.
- 53-63 Silt, as above, clayey, less sand, with thin (less than 1 foot) siltstone to mudstone lenses.
- 63-80 Silt, very clayey, steel-gray to bluish, moderately indurated, very dense.  
Cannonball-Ludlow Formations.

Wells 30, 31, 32 and 33

- 0-1 Top soil, silty, sandy, brownish, calcareous; with some granite and limestone pebbles.
- 1-2 Pebble-loam (glacial till), silty, sandy, clayey, yellowish-brown, dry, calcareous.
- 2-31 Silt, clayey, with minor amounts (less than 10%) of very fine-grained sand interspersed, brownish-tan, slightly indurated, calcareous, oxidized; with small iron oxide concretions. Some small, black flakes organic plant material.  
Cannonball-Ludlow Formations.
- 31-44 Silt, clayey, steel-gray (color change), slightly indurated, calcareous; with small iron oxide concretions, thin coarse silt lenses, small gypsum crystals and gray to reddish-brown mottling.

- 44-61 Silt, as above, with some (less than 20%) fine- to medium-grained sand interspersed.
- 61-65 Silt, as above, with abundant (more than 20%) fine- to medium-grained sand interspersed, dense.
- 65-76 Silt, as above, clayey, less sand, some thin (less than 1 foot) lenses of siltstone to mudstone.
- 76-80 Siltstone, sandy, clayey, steel-gray to bluish, slightly indurated; with small fine-grained sand lenses and abundant (more than 20%) fine-grained sand interspersed in the matrix.
- 80-92 Silt, clayey, steel-gray to bluish, moderately indurated, with some (less than 20%) very fine- to fine grained sand interspersed.
- 92-120 Silt, very clayey, steel-gray to bluish, moderately indurated, very dense.  
Cannonball-Ludlow Formations.
- Well 40
- 0-1 Top soil, sandy, silty, brownish-tan, calcareous; with some granite and limestone pebbles.
- 1-5 Pebble-loam (glacial till), sandy, silty, with detrital lignite and organic matter, yellowish-brown, very dry, calcareous.
- 5-22 Sand, very fine- to medium-grained, unconsolidated, with thin lenses of clay and detrital lignite, brownish-yellow, calcareous.
- 22-40 Silt, clayey, with minor amounts (less than 10%) very fine-grained sand interspersed, brownish-tan, slightly indurated, calcareous, oxidized; with small iron oxide concretions and small gypsum crystals; Cannonball-Ludlow Formations.
- 40-51 Silt, clayey, with minor amounts (less than 10%) of very fine-grained sand interspersed, steel-gray (color change), moderately indurated; with some reddish-brown mottling and some very thin (less than 6 inches) mudstone lenses.
- 51-58 Silt, as above, with abundant (more than 20%) fine-grained sand and thin silty-clay lenses.



- 58-62 Siltstone, sandy, clayey, steel-gray to bluish, moderately indurated; with small fine-grained sand lenses and abundant (more than 20%) sand interspersed in the matrix.
- 62-70 Silt, clayey, with some (less than 20%) fine- to medium-grained sand interspersed, steel-gray to bluish, moderately indurated; with thin (less than 2 feet) sandy lenses.
- 70-80 Silt, as above, very clayey, some (less than 10%) fine-grained sand interspersed; less sand than above interval.
- 80-120 Silt, as above, dark-steel-gray.  
Cannonball-Ludlow Formations.

Wells 41, 42 and 43

- 0-1 Top soil, sandy, silty, dark-brown, calcareous; with some granite and limestone pebbles.
- 1-4 Pebble-loam (glacial till), sandy, silty, clayey, yellowish-brown, very dry, calcareous.
- 4-40 Silt, clayey, with some (less than 20%) very fine-grained sand interspersed, brownish-tan, unconsolidated, noncompacted, calcareous to 25 feet, oxidized; with small iron oxide concretions and abundant small gypsum crystals.  
Cannonball-Ludlow Formations.
- 40-51 Silt, clayey, with minor amounts (less than 10%) of very fine-grained sand interspersed, steel-gray (color change), moderately indurated; with some reddish-brown mottling and some very thin (less than 6 inches) mudstone lenses.
- 51-58 Silt, as above, with abundant (more than 20%) fine-grained sand and thin silty-clay lenses.
- 58-62 Siltstone, sandy, clayey, steel-gray to bluish, moderately indurated; with small fine-grained sand lenses and abundant (more than 20%) sand interspersed in the matrix.
- 62-70 Silt, clayey, with some (less than 20%) fine- to medium-grained sand interspersed, steel-gray to bluish, moderately indurated; with thin (less than 2 feet) sandy lenses.

- 70-80 Silt, as above, very clayey, some (less than 10%) fine-grained sand interspersed; less sand than above interval.

Wells 43 and 44

- 0-2 Top soil, clayey, silty, some sand, brownish-tan to light-gray, calcareous.
- 2-20 Silt, clayey, with some (less than 20%) fine-grained sand interspersed, brownish-tan, slightly indurated, very dry, calcareous; with small iron oxide concretions, abundant small gypsum crystals and occasional thin silt lenses. Cannonball-Ludlow Formations.
- 20-25 Silt, as above, very clayey, oxidized, with minor amounts (less than 10%) of fine-grained sand.
- 25-35 Silt, as above, dark-brownish-tan to bluish-gray (color change), with thin very fine-grained sand lenses.
- 35-60 Silt, clayey, with some (less than 20%) fine- to medium-grained sand interspersed, steel-gray to bluish, moderately indurated; with some indurated silty sand lenses. Cannonball-Ludlow Formations.

Wells 50, 51 and 52

- 0-4 Top soil, clayey, silty, very dark-brown.
- 4-10 Clay, silty, with some (less than 20%) fine-grained sand, dark-brownish-tan, soft, cohesive, wet, sticky; with some pebbles.
- 10-22 Silt, very clayey, with some (less than 20%) very fine-grained sand interspersed, brownish-tan, slightly indurated, calcareous, dense; with abundant small gypsum crystals and very thin silt and sand lenses; Cannonball-Ludlow Formations.
- 22-23 Sandstone, fine-grained, silty, indurated, oxidized, dark-brown.
- 23-30 Silt, very clayey, with some (less than 20%) very fine-grained sand interspersed, steel-gray (color change), moderately indurated; with thin medium grained sand lenses.

- 30-40 Silt, as above, very clayey, less sand than above interval, dark-steel-gray.  
Cannonball-Ludlow Formations.

Wells 53 and 54

- 0-4 Top soil, clayey, silty, very dark-brown, wet, sticky.
- 4-15 Clay, silty, with some (less than 20%) fine- to medium-grained sand interspersed, brownish-tan, slightly indurated, dry, calcareous; with small iron oxide concretions, small gypsum crystals and occasional reddish-brown mottling;  
Cannonball-Ludlow Formations.
- 15-20 Sand, very fine-grained to medium-grained, silty, clayey, unconsolidated, yellowish-brown, oxidized.
- 20-30 Silt, clayey, with some (less than 20%) fine-grained sand interspersed, steel-gray (color change), slightly indurated; with clay and sand lenses, some small concretions and some small gypsum crystals.
- 30-45 Silt, as above, very clayey.
- 45-60 Silt, as above, clayey, brownish-gray, moderately indurated, some reddish-brown mottling.  
Cannonball-Ludlow Formations.

Wells 55 and 56

- 0-5 Sandy-loam (glacial), with fine- to medium-grained sand, silty, calcareous; with small granite and limestone pebbles.
- 5-26 Clay, silty, with minor amounts (less than 10%) of very fine-grained sand, dark-brownish-tan, moderately indurated, brittle, very dry, calcareous; with small iron oxide concretions, small gypsum crystals and occasional thin sandstone laminae. Some small, black flakes of organic plant material.  
Cannonball-Ludlow Formations.
- 26-35 Clay, as above, very silty, sandy, brownish-tan, oxidized.

- 35-40 Silt, clayey, with some (less than 20%) very fine- to fine-grained sand interspersed, steel-gray (color change) moderately indurated; with small gypsum crystals and occasional clay lenses.
- 40-60 Silt, as above, with minor amounts (less than 10%) of fine-grained sand interspersed.
- 60-85 Silt, as above, clayey, less sand than above interval.
- 85-100 Silt, as above, very clayey, with minor amounts (less than 10%) of sand interspersed, light-gray. Cannonball-Ludlow Formations.

Wells 60, 61 and 62

- 0-2 Top soil, silty, clayey, dark-brown to tanish-brown, calcareous.
- 2-25 Silt, very clayey, with some minor amounts (less than 10%) of very fine- to fine-grained sand interspersed, brownish-tan, slightly indurated, dry, calcareous; with abundant small gypsum crystals and thin silt and sand lenses; Cannonball-Ludlow Formations.
- 25-29 Silt, as above, with abundant (more than 20%) fine- to medium-grained sand interspersed.
- 29-36 Silt, as above, clayey, less sand than above interval, dark-brownish-tan, oxidized.
- 36-60 Silt, very clayey, with some (less than 20%) very fine-grained sand interspersed, steel-gray (color change), moderately indurated; with thin (less than 1 foot) sandy-silt lenses. Cannonball-Ludlow Formations.

Well 70 0-2 Pebble-loam (glacial till), clayey, sandy, yellowish-brown, unconsolidated, damp, calcareous.

- 2-21 Silty, clayey, with some (less than 20%) fine-grained sand interspersed, brownish-tan, moderately indurated, very dry, calcareous, oxidized; with small iron oxide concretions and abundant small gypsum crystals. Cannonball-Ludlow Formations.

- 21-24 Shale, silty, steel- to dark-gray (color change), indurated, fissile, very dry; with occasional thin silt and sand lenses.
- 24-31 Silt, clayey, with abundant (more than 30%) sand, steel-gray, moderately indurated.
- 31-62 Silt, clayey, with some (less than 20%) very fine- to fine- grained sand interspersed, steel-gray, moderately indurated; with some small gypsum crystals and small iron oxide concretions.
- 62-76 Silt, as above, with some (less than 20%) fine-grained sand interspersed.
- 76-82 Silt, as above, with abundant (more than 20%) fine- to medium-grained sand.
- 82-100 Silt, as above, clayey, with some (less than 20%) fine-grained sand interspersed, dark-gray.  
Cannonball-Ludlow Formations.

The lithologic logs for wells 80-87 were described by personal from Water Supply Incorporated (W.S.), Bismarck, North Dakota. The wells were installed during a previous ground water investigation at Heskett Station.

Well 80 (W.S. 2)

0-1	Top soil, silty, black.
1-4	Pebble-loam (glacial till), silty, clayey, some cobbles, yellowish-brown.
4-7	Gravel, sand and rocks.
7-21	Sand, fine- to coarse-grained, some pebbles.
21-39	Clay, silty, sandy, yellowish-brown to gray.
39-52	Clay, silty, sandy, gray.
52-67	Sand, fine-grained, bluish, with some clay layers.
67-89	Clay, silty, sandy, brown to gray.

Wells 81, 82 and 83 (W.S. 1, 1A and 1B)

0-1	Top soil, silty, black.
1-4	Clay, (glacial), silty, with pebbles, yellowish-brown.
4-21	Sand, fine- to medium-grained, yellowish-brown; with clay and silt lenses.
21-25	Clay, silty, yellowish-brown.
25-30	sand, fine-grained, yellowish-brown, some indurated layers.
30-35	Clay, silty, yellowish-brown.
35-45	Sand, fine-grained, yellowish-brown.
45-50	Clay, silty, sandy, gray, about 50 percent shale.
50-56	Sand, fine-grained, with clay layers.
56-73	Clay, silty, sandy, gray.

Wells 83, 84 and 85 (W.S. 4, 4A and 4B)

0-13	Pebble-loam (glacial till), silty, sandy, with some cobbles, yellowish-brown.
13-23	Sand, fine- to medium-grained, yellowish-brown.
23-25	Clay, silty, sandy, yellowish-brown.
25-27	Sandstone, indurated.
27-30	Clay, sandy, silty, gray.
30-36	Sand, fine-grained, gray.
36-52	Clay, silty, sandy, gray; with some sand layers.

Wells 86 and 87 (W.S. 3 and 3A)

0-1	Top soil, silty, black.
1-12	Pebble-loam, clayey, silty, with some cobbles, yellowish-brown.
12-16	Clay, silty, gray; with some shale layers.
16-18	Limestone, indurated.
18-23	Clay, silty, yellowish-brown; with some sand layers.

- 23-44 Sand, fine- to medium-grained, gray; with some clay layers.  
 44-50 Clay, silty, medium-gray.

The lithologic logs for wells 90-94 were described by personal from Dames and Moore Inc., Bismarck, North Dakota. The wells were installed at the Mandan Amoco Refinery (AM) during a previous ground water investigation.

Well 90 (AM 26-81)

- 0-1 Clay, silty, black.  
 1-6 Clay, silty, yellowish-brown; with some fine sand.  
 6-29 Clay, silty, light-brown to tan; with occasional sandy layers.  
 29-36 Clay, silty, dark-gray to gray.

Well 91 (AM 28-81)

- 0-1 Clay, silty, black.  
 1-3 Clay, silty, light-brown to tan.  
 3-21 Clay, silty, light-brown to tan.  
 21-30 Clay, silty, dark-gray to gray.

Wells 92 and 93 (AM 30-S-81 and 30-D-81)

Well logs not available.

Well 94 (AM 32-81)

- 0-1 Silt, fine sandy, black.  
 1-8 Clay, silty, yellowish-brown.  
 8-16 Sand, fine- to medium-grained, light brown.  
 16-33 Clay, silty, light-brown; with occasional fine sand lenses.  
 33-40 Clay, silty, dark-gray to steel gray.  
 40-42 Sandstone, fine, bluish-gray, soft.  
 42-46 Clay, silty, dark-gray.  
 46-50 Sandstone, fine, bluish-gray, soft.

APPENDIX D  
Ground Water Chemical Analysis of  
Selected Heskett Site Wells



## Chemical Analyses of Selected Wells

Parameter	Well 10	Well 12	Well 30
Sample Collection Date	9-11-86	9-11-86	9-11-86
Water Level <sup>1</sup> (ft)	51.6	42.4	49.4
Elevation; Screen Center (ft)	1606.0	1653.5	1597.6
Field Water Temp (°C)	8.0	8.4	8.0
Field pH (standard units)	7.6	7.2	8.1
Field Sp.Cond. (umhos/cm)	7370.0	8070.0	1350.0
Total Dissolved Solids <sup>2</sup> (mg/L)	9736.0	10396.0	1286.0
Total Alkalinity as CaCO <sub>3</sub> (mg/L)	674.0	645.0	425.0
Bicarbonate (HCO <sub>3</sub> ) (mg/L)	825.0	789.0	520.0
Boron (B) (mg/L)			
Calcium (Ca) (mg/L)	339.0	422.0	33.0
Chloride (Cl) (mg/L)	20.8	20.7	2.1
Fluoride (F) (mg/L)	0.3	<.2	0.4
Iron (Fe) (mg/L)	<.2	0.6	<.2
Potassium (K) (mg/L)	16.0	13.0	5.8
Magnesium (Mg) (mg/L)	302.0	318.0	34.0
Nitrate (NO <sub>3</sub> ) (mg/L)	<1	<1	<1
Sodium (Na) (mg/L)	2232.0	2438.0	352.0
Sulfate (SO <sub>4</sub> ) (mg/L)	6443.0	6818.0	606.0
TRACE ELEMENTS:			
Arsenic (Ar) (mg/L)	<.002	.0025	<.002
Barium (Ba) (mg/L)	0.090	0.157	0.030
Cadmium (Cd) (mg/L)	0.0020	0.0012	<.001
Chromium (Cr) (mg/L)	<.002	<.002	<.002
Lead (Pb) (mg/L)	<.002	<.002	<.002
Manganese (Mn) (mg/L)	0.986	2.130	0.124
Mercury (Hg) (mg/L)	<.0003	<.0003	<.0003
Molybdenum (Mo) (mg/L)	0.018	<.010	<.010
Selenium (Se) (mg/L)	<.002	<.002	<.002
Silver (Ag) (mg/L)	<.001	<.001	<.001

<sup>1</sup>From top of PCV casing.

<sup>2</sup>TDS is calculated.

## Chemical Analyses of Selected Wells

Parameter		Well 32	Well 40	Well 42
Sample Collection Date		9-11-86	9-11-86	9-11-86
Water Level <sup>1</sup>	(ft)	42.5	63.8	33.3
Elevation; Screen Center	(ft)	1651.7	1594.3	1662.6
Field Water Temp	(°C)	8.3	8.6	8.5
Field pH	(standard units)	6.9	7.5	7.0
Field Sp. Cond.	(umhos/cm)	3150.0	4290.0	3700.0
Total Dissolved Solids <sup>2</sup>	(mg/L)	3927.0	5333.0	4658.0
Total Alkalinity as CaCO <sub>3</sub>	(mg/L)	467.0	565.0	424.0
Bicarbonate (HCO <sub>3</sub> )	(mg/L)	571.0	691.0	519.0
Boron (B)	(mg/L)			
Calcium (Ca)	(mg/L)	313.0	422.0	432.0
Chloride (Cl)	(mg/L)	10.0	15.2	46.8
Fluoride (F)	(mg/L)	0.3	0.2	0.3
Iron (Fe)	(mg/L)	<.2	<.2	0.3
Potassium (K)	(mg/L)	14.0	12.0	15.0
Magnesium (Mg)	(mg/L)	318.0	136.0	250.0
Nitrate (NO <sub>3</sub> )	(mg/L)	<1	<1	4.3
Sodium (Na)	(mg/L)	464.0	1047.0	648.0
Sulfate (SO <sub>4</sub> )	(mg/L)	2538.0	3378.0	3058.0
TRACE ELEMENTS:				
Arsenic (Ar)	(mg/L)	<.002	<.002	<.002
Barium (Ba)	(mg/L)	0.093	0.083	0.198
Cadmium (Cd)	(mg/L)	<.001	<.001	<.001
Chromium (Cr)	(mg/L)	<.002	<.002	<.002
Lead (Pb)	(mg/L)	<.002	<.002	<.002
Manganese (Mn)	(mg/L)	0.462	0.037	0.670
Mercury (Hg)	(mg/L)	<.0003	<.0003	<.0003
Molybdenum (Mo)	(mg/L)	0.014	<.010	<.010
Selenium (Se)	(mg/L)	<.002	0.005	0.032
Silver (Ag)	(mg/L)	<.001	<.001	<.001

<sup>1</sup>From top of PCV casing.

<sup>2</sup>TDS is calculated.

## Chemical Analyses of Selected Wells

Parameter		Well 44	Well 50	Well 50
Sample Collection Date		11-21-86	9-11-86	11-21-86
Water Level <sup>1</sup>	(ft)	21.85	5.5	4.17
Elevation; Screen Center	(ft)	1687.9	1657.5	1657.5
Field Water Temp	(°C)	6.5	9.7	8.5
Field pH	(standard units)	6.76	7.5	7.37
Field Sp. Cond.	(µmhos/cm)	7580.0	4310.0	3620.0
Total Dissolved Solids <sup>2</sup>	(mg/L)	11240.0	4999.0	5196.0
Total Alkalinity as CaCO <sub>3</sub>	(mg/L)	401.0	418.0	416.0
Bicarbonate (HCO <sub>3</sub> )	(mg/L)	491.0	511.0	509.2
Boron (B)	(mg/L)			
Calcium (Ca)	(mg/L)	648.0	313.0	391.0
Chloride (Cl)	(mg/L)	558.0	34.8	33.0
Fluoride (F)	(mg/L)	0.5	0.3	<0.2
Iron (Fe)	(mg/L)	<0.2	<.2	<0.2
Potassium (K)	(mg/L)	51.0	12.0	13.0
Magnesium (Mg)	(mg/L)	1322.0	250.0	257.0
Nitrate (NO <sub>3</sub> )	(mg/L)	30.0	23.5	112.0
Sodium (Na)	(mg/L)	1589.0	871.0	902.0
Sulfate (SO <sub>4</sub> )	(mg/L)	7390.0	3302.0	3384.0
TRACE ELEMENTS:				
Arsenic (Ar)	(mg/L)	<.002	<.002	<.002
Barium (Ba)	(mg/L)	0.156	0.084	0.128
Cadmium (Cd)	(mg/L)	<.001	<.001	<.001
Chromium (Cr)	(mg/L)	<0.001	<.002	0.003
Lead (Pb)	(mg/L)	<.005	<.002	<.005
Manganese (Mn)	(mg/L)	0.218	0.010	0.005
Mercury (Hg)	(mg/L)	<.0003	<.0003	<.0003
Molybdenum (Mo)	(mg/L)	<.010	<.010	<.010
Selenium (Se)	(mg/L)	0.086	0.055	0.076
Silver (Ag)	(mg/L)	<.002	<.001	<.002
Phenol	(mg/L)	<1.0	<1.0	<1.0
Oil & Grease	(mg/L)	<3.0	<3.0	<3.0

<sup>1</sup>From top of PCV casing.

<sup>2</sup>TDS is calculated.

## Chemical Analyses of Selected Wells

Parameter	Well 52	Well 54	Well 55
Sample Collection Date	11-21-86	11-21-86	11-21-86
Water Level <sup>1</sup> (ft)	4.07	20.97	29.50
Elevation; Screen Center (ft)	1663.0	1635.1	1648.9
Field Water Temp (°C)	8.7	6.9	7.5
Field pH (standard units)	7.38	8.03	6.81
Field Sp. Cond. (µmhos/cm)	4650.0	4570.0	9007.0
Total Dissolved Solids <sup>2</sup> (mg/L)	6072.0	7223.0	13081.0
Total Alkalinity as CaCO <sub>3</sub> (mg/L)	424.0	616.0	528.0
Bicarbonate (HCO <sub>3</sub> ) (mg/L)	519.0	754.0	646.3
Boron (B) (mg/L)			
Calcium (Ca) (mg/L)	392.0	295.0	445.0
Chloride (Cl) (mg/L)	45.0	92.0	81.0
Fluoride (F) (mg/L)	<0.2	0.3	0.7
Iron (Fe) (mg/L)	<0.2	<0.2	<0.2
Potassium (K) (mg/L)	15.0	13.0	28.0
Magnesium (Mg) (mg/L)	305.0	439.0	862.0
Nitrate (NO <sub>3</sub> ) (mg/L)	148.0	6.0	154.0
Sodium (Na) <sup>3</sup> (mg/L)	1115.0	1490.0	2423.0
Sulfate (SO <sub>4</sub> ) (mg/L)	3991.0	4617.0	9007.0
TRACE ELEMENTS:			
Arsenic (Ar) (mg/L)	<.002	<.002	<.002
Barium (Ba) (mg/L)	0.125	0.105	0.133
Cadmium (Cd) (mg/L)	<.001	<.001	<.001
Chromium (Cr) (mg/L)	0.003	0.003	0.003
Lead (Pb) (mg/L)	<.005	<.005	<.005
Manganese (Mn) (mg/L)	0.004	1.080	0.045
Mercury (Hg) (mg/L)	<.0003	<.0003	<.0003
Molybdenum (Mo) (mg/L)	<.010	0.041	<.010
Selenium (Se) (mg/L)	0.088	0.025	0.386
Silver (Ag) (mg/L)	<.002	<.002	<.002
Phenol (mg/L)		<1.0	
Oil & Grease (mg/L)		<3.0	

<sup>1</sup>From top of PCV casing.

<sup>2</sup>TDS is calculated.

## Chemical Analyses of Selected Wells

Parameter		Well 60	Well 70
Sample Collection Date		11-21-86	9-11-86
Water Level <sup>1</sup>	(ft)	32.35	55.0
Elevation; Screen Center	(ft)	1677.0	1636.4
Field Water Temp	(°C)	7.6	8.6
Field pH	(standard units)	6.83	8.3
Field Sp. Cond.	(µmhos/cm)	10440.0	10370.0
Total Dissolved Solids <sup>2</sup>	(mg/L)	14917.0	13129.0
Total Alkalinity as CaCO <sub>3</sub>	(mg/L)	540.0	491.0
Bicarbonate (HCO <sub>3</sub> )	(mg/L)	661.0	600.0
Boron (B)	(mg/L)		
Calcium (Ca)	(mg/L)	417.0	192.0
Chloride (Cl)	(mg/L)	208.0	10.9
Fluoride (F)	(mg/L)	0.5	0.3
Iron (Fe)	(mg/L)	<0.2	<.2
Potassium (K)	(mg/L)	41.0	22.0
Magnesium (Mg)	(mg/L)	1355.0	121.0
Nitrate (NO <sub>3</sub> )	(mg/L)	170.0	<1
Sodium (Na)	(mg/L)	1148.0	3682.0
Sulfate (SO <sub>4</sub> )	(mg/L)	11632.0	8818.0
TRACE ELEMENTS:			
Arsenic (Ar)	(mg/L)	<.002	.0032
Barium (Ba)	(mg/L)	0.151	0.080
Cadmium (Cd)	(mg/L)	<.001	0.0010
Chromium (Cr)	(mg/L)	0.004	<.002
Lead (Pb)	(mg/L)	<.005	<.002
Manganese (Mn)	(mg/L)	0.033	0.110
Mercury (Hg)	(mg/L)	<.0003	<.0003
Molybdenum (Mo)	(mg/L)	<.010	0.017
Selenium (Se)	(mg/L)	0.195	<.002
Silver (Ag)	(mg/L)	<.002	<.001
Phenol	(mg/L)	<1.0	
Oil & Grease	(mg/L)	<3.0	

<sup>1</sup>From top of PCV casing.

<sup>2</sup>TDS is calculated.

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